

RESEARCH REPORT

N-8617 : RR 89-2
ENGINEERED CONTROL PARAMETER FOR
AUTOMATED MINE VENTILATION
FINAL REPORT

by

J-P Saindon

Work on the project was conducted under the auspices of the Canada Centre for
Mineral and Energy Technology, Energy, Mines and Resources, Canada.

DSS FILE NUMBER: 07SQ.23440-7-9040
DSS CONTRACT SERIAL NUMBER: 23440-7-9040/01-SQ
CANMET SCIENTIFIC AUTHORITY: Dr. M. Gangal

November 1989

290 ff

Centre de Recherche Noranda
240 Boulevard Hymus
Pointe Claire, Quebec
H9R 1G5

MICROMEDIA

DISTRIBUTION

M. Gangal (CANMET) (5 copies)

D. Dainty (CANMET)

F. Hermann (BMS-M) (5 copies)

J-P Saindon

F. Lederman/J. Nantel/Library

K.G. Wheeland/Dept. File

Library

ACKNOWLEDGEMENTS

The present work was supported in part by EMR through the unsolicited proposal fund. I would like to thank Canmet for their support, in particular Mahe Gangal and Don Dainty, who were very helpful in the first survey of Phase I and supportive throughout the project.

The collaboration and support of BMS-M was a key to the successful completion of this report. I am grateful to Dale Petrie (Ventilation Supervisor) and his team, Fred Hermann (Chief Engineer) and Matthew Laplante (Head of the Energy Conservation Dept.) for their assistance.

Last, but not least, I would like to thank my colleagues at NTC and Decibel Consultants Inc. who have assisted me in the field work.

KEY WORDS

Monitoring Strategy

CO₂ Surrogate

Automated Mine Ventilation

Control Parameter

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
SOMMAIRE	2
 <u>PHASE I - UNDERGROUND CONTAMINANTS SURVEYS</u>	
1. INTRODUCTION	4
2. BACKGROUND	5
2.1 General	5
2.2 CO ₂ as a Surrogate	6
3. FIRST FIELD SURVEY AT BMS-M	10
3.1 Objective	10
3.2 Monitoring Strategy	10
3.3 Presentation of Results	18
3.4 Discussion of Results	22
3.4.1 Continuous Gas Results	22
3.4.2 Correction to Exhaust Data	27
3.4.3 TWA Measurements	27
3.4.4 Reliability of Instrumentation	27
3.4.5 Slope of Characteristic Curves	34
3.4.6 Factors Affecting an Automated System	34
4. CONTROL PARAMETER: CO ₂ SURROGATE	35
5. CONCLUSIONS OF FIRST FIELD SURVEY	38
6. RECOMMENDATIONS OF FIRST FIELD SURVEY	39

TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
7. SECOND FIELD SURVEY AT BMS-M	39
7.1 Objectives	39
7.2 Monitoring Strategy	40
7.3 Results	45
7.3.1 Propane Burners	45
7.3.2 1000 mL Sill Results	47
7.3.3 1000 mL No. 2 Sub Results	56
7.3.4 1000 mL V-4 Exhaust Results	62
7.3.5 Oil Mist Study	62
8. CONCLUSIONS	69
REFERENCES	104
APPENDICES	
APPENDIX A	- CO ₂ AND CONTAMINANTS CORRELATIONS
	- A-1 - NO vs CO ₂
	- A-2 - CO vs CO ₂
	- A-3 - NO ₂ vs CO ₂
	- A-4 - SO ₂ vs CO ₂

TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
<u>PHASE II - EVALUATION OF VENTILATION CONTROL OPTIONS</u>	
1. INTRODUCTION	73
2. MINE VENTILATION CONTROL TECHNIQUES	73
3. PROPOSED CONTROL STRATEGY FOR BMS-M	75
3.1 Control of Auxiliary Ventilating Fans	75
3.2 Control of the Main Ventilation Network	76
3.3 Control System Design	77
3.3.1 Central Computer	78
3.3.2 Communication System	78
3.3.3 Final Control Elements	80
3.3.3.1 Fan Control	80
3.3.3.2 Main Surface Fans Control	86
3.3.3.3 Booster Fans	86
3.3.3.4 Propane Burners Control	87
3.3.3.5 Regulating Doors	87
3.3.3.6 Position Encoder Specifications	91
3.3.4 Airflow Measurement	91
3.4 Control Considerations	92
3.4.1 Open Loop Control	96
3.4.2 Closed Loop Control	98
3.5 Capital Investment	99
4. CONCLUSIONS AND RECOMMENDATIONS	102
REFERENCES	104

v

TABLE OF CONTENTS (Cont'd)

APPENDIX B	POWER LINE CARRIER SYSTEM INFORMATION
APPENDIX C	CONTROLLER INFORMATION ON MAIN SURFACE FANS
APPENDIX D	CONTROLLER INFORMATION ON BOOSTER FANS
APPENDIX E	INFORMATION OF CONTROLLABLE REGULATING DOORS
APPENDIX F	AIRFLOW SENSORS INFORMATION
APPENDIX G	BMS-M COMPUTERIZED VENTILATION NETWORK
APPENDIX H	FIX SCADA SYSTEM

LIST OF TABLES

	<u>Page</u>
<u>PHASE I - UNDERGROUND CONTAMINANTS SURVEYS</u>	
Table I - Instrumentation List	12
Table II - Linear Regression Analysis	23
Table III - TWA Results	24
Table IV - TWA and Continuous Results Comparison	31
Table V - Instrumentation List	41
Table VI - Time Weighted Concentration of Oil Mist	68
<u>PHASE II - EVALUATION OF VENTILATION CONTROL OPTIONS</u>	
Table VII - Open-Loop Ventilation Network Control	100
Table VIII - Closed-Loop Upgrade	101

LIST OF FIGURES

<u>PHASE I - UNDERGROUND CONTAMINANTS SURVEYS</u>		
Figure 1	-	CFM/BHP vs Diesel Produced CO ₂ 7
Figure 2	-	Plot of Emitted CO vs CO ₂ 8
Figure 3	-	Pollutant Characteristic Curve of CO vs CO ₂ 9
Figure 4	-	Ventilation Plan, 1000 Level 13
Figure 5	-	Ventilation Plan, 1000 Level, No. 1 Sub 14

LIST OF FIGURES (Cont'd)

		<u>Page</u>
Figure 6	- Ventilation Plan, 725 Level, Sill	15
Figure 7	- Ventilation Plan, 725 Level, No. 1 Sub	16
Figure 8	- Ventilation Plan, 725 Level, No. 2 Sub	17
Figure 9	- Graph of Contaminants vs Time, 4 November 1987	19
Figure 10	- Graph of Contaminants vs Time, 5 November 1987	20
Figure 11	- Graph of Contaminants vs Time, 11 November 1987	21
Figure 12	- 725 Level Exhaust Correlation (NO/CO ₂)	32
Figure 13	- 1000 Level Exhaust Correlation (NO/CO ₂)	33
Figure 14	- 1000 mL Ventilation Schematic	42
Figure 15	- 1000 mL Sill, Stations Set-Up	43
Figure 16	- No. 2 Sub Set-Up	44
Figure 17	- CO/NO/CO ₂ Emission, V-5 Intake	46
Figure 18	- CO/CO ₂ Emission, V-5 Intake	48
Figure 19a	- CO Emission, Scoop VL184 (Day Shift)	49
Figure 19b	- CO Emission, Scoop VL184 (Afternoon Shift)	49
Figure 20a	- CO Emission, Truck VH151 (Day Shift)	51
Figure 20b	- CO Emission, Truck VH151 (Afternoon Shift)	51

LIST OF FIGURES (Cont'd)

		<u>Page</u>
Figure 21	- CO/NO/CO ₂ Emission, 1000 South Exhaust (Day Shift)	52
Figure 22	- CO/NO/CO ₂ Emission, 1000 South Exhaust (Afternoon Shift)	53
Figure 23	- CO/NO/CO ₂ Emission, 1000 South Exhaust (Graveyard Shift)	54
Figure 24	- NO/CO Emission, 1000 South Exhaust (Afternoon Shift)	55
Figure 25	- CO/NO/CO ₂ Emission, 1000 South Exhaust (Graveyard Shift)	57
Figure 26	- CO/NO/CO ₂ Emission, 1000 South Access (Graveyard Shift)	58
Figure 27	- CO/NO/CO ₂ Emission, 1000 South Access (Afternoon Shift)	59
Figure 28	- CO/NO/CO ₂ Emission, 1000 2 Sub Exhaust (Afternoon Shift)	60
Figure 29	- CO/NO/CO ₂ Emission, 1000 2 Sub Exhaust (Day Shift)	61
Figure 30	- CO/NO/CO ₂ Emission, V-4 Exhaust (Afternoon Shift)	63
Figure 31	- CO/NO/CO ₂ Emission, V-4 Exhaust (Graveyard Shift)	64
Figure 32	- CO/NO/SO ₂ Emission, V-4 Exhaust (Graveyard Shift)	65
Figure 33	- CO/NO/SO ₂ Emission, V-4 Exhaust (Day Shift)	66
Figure 34	- CO/NO/SO ₂ Emission, V-4 Exhaust (Day Shift)	67
Figure 34b	- Sensitivity of NO Sensor	71

LIST OF FIGURES (Cont'd)PagePHASE II - EVALUATION OF VENTILATION

Figure 35	-	Communication System Design	79
Figure 36	-	Air Performance Data of Variable Pitch-in-motion Fan	81
Figure 37	-	Air Performance Data With Corresponding Energy Requirements	82
Figure 38	-	Wood Colchester Varofoil Control Hub	84
Figure 39	-	Power Consumption Curve and Schematic of SER	85
Figure 40	-	VDI Orifice and Discharge Coefficients	89
Figure 41	-	Flow Position Characteristics	90
Figure 42	-	Closed Loop Regulator Control	93
Figure 43	-	Response of Regulator Control Under Sudden Resistance Change	95
Figure 44	-	Central Computer / Human Interface	97

SUMMARY

The research for the following report was funded by BMS-M and CANMET through the unsolicited proposal funds, and had as its objective the evaluation of the potential for closed-loop mine ventilation control using CO₂ as the primary indicator of air quality in a dieselized mine. The research and the report were divided into two phases.

In Phase I, two underground contaminant surveys were undertaken by Noranda Technology over a period of four weeks in November 1987 and February 1989. The objective was to verify if a linear relationship was a valid assumption for CO₂ vs diesel contaminants in a highly mechanized operation. Several researchers have shown that linear relationships exist between CO₂ and the other diesel pollutants for a single machine operating in a controlled environment. If the relationship holds true for a normal diesel-intensive operation, it may be possible to use CO₂ as the major control parameter in an automated mine ventilation system.

The relationships established from the collected data demonstrated the linearity between NO, CO₂ and CO. Results for other pollutants were affected by the low levels present in the mine atmosphere and the limitations of sensing equipment.

The CO₂ sensors performed well and responded within 5 seconds to small changes in concentration. However, the slope of the linear relationship between NO, CO₂ and CO was affected by factors such as diesel equipment composition, propane burners and blasting.

In Phase II, the principles of conventional control were reviewed and their application to ventilation control evaluated. Ventilation automation is a unique problem which requires control from a central location based on a relational database or a linear/nonlinear flow model. The control must be based on steady-state flow.

The components required for control (communication system, computer hardware and control elements) are detailed in this report. Open-loop vs closed-loop control of ventilation is also presented.

From the data acquired from Phase I and II, Noranda Technology Centre recommends first the implementation of an open-loop ventilation network control and to demonstrate that stable conditions can be maintained under steady-state changes.

Fully automated closed loop control may not be achievable due to the difficulty of using CO₂ alone for feedback control. Implementation of a combination of open and closed loop is recommended once the open loop has been fully demonstrated. In this approach, the ventilation would still be determined by the forecasted diesel requirements for the shift, and gas analyses from various levels would identify under-ventilation areas (over-ventilated areas will not be modified). These areas could be provided with more air in mid-shift.

SOMMAIRE

La recherche pour ce rapport a été supportée par Mine Brunswick et CANMET (à partir d'une demande non sollicitée par NTC). Elle a pour objectif d'évaluer le potentiel du contrôle de la ventilation en Boucle fermée à partir de lectures de CO_2

Le présent rapport est présenté en deux parties:

Dans la phase I, deux études de terrain ont été entreprises par le Centre de Technologie Noranda en novembre 1987 et février 1989. Ces études avaient pour objectif de vérifier la validité de la relation linéaire entre les émissions de contaminants diésels dans une opération minière mécanisée. Plusieurs scientifiques ont démontré l'existence d'une relation linéaire entre le CO_2 et les contaminants diésels pour un unité diesel opérant dans un environnement contrôlé. Si cette relation demeure vraie à l'échelle de la mine, il pourrait être possible d'utiliser le CO_2 comme paramètre de contrôle dans un système de ventilation automatisé.

La relation établie à partir des données de terrain démontre qu'il existe une linéarité entre le NO , CO_2 et CO . Les faibles concentrations présentes dans l'atmosphère minier et les limitations des capteurs n'ont pas permis de démontrer la linéarité des autres contaminants (NO_2 , SO_2 et RCD).

Les détecteurs de CO_2 ont performé très bien et pourrait être installé avec succès souterrain pour la détection en continu. Par contre, la pente de la régression linéaire entre le NO , CO_2 et CO est affectée par la composition de la flotte diésel, les brûleurs au propane et le sautage, ce qui limite l'application exclusive du détecteur de CO_2 pour déterminer la qualité de l'air.

Dans la phase II, les principes du contrôle conventionnel sont révisés et leur applications pour l'automatisation de la ventilation sont évaluées. L'automatisation de la ventilation est un problème unique qui requiert le contrôle à partir d'un ordinateur central basé sur un modèle d'écoulement non linéaire ainsi qu'une base de données relationnelle.

Les composantes requises pour le contrôle (système de communication, ordinateur et éléments de contrôle) sont détaillées dans ce rapport. Le contrôle de la ventilation en boucle ouverte et fermée est également présenté.

A partir des données acquises dans la phase I et II, le Centre de Technologie Noranda recommande l'implantation d'un système de contrôle en boucle ouverte.

Ce système devra démontrer qu'il est possible de maintenir des conditions de ventilation stables lors de changements automatisés de la distribution d'air.

Un système en boucle fermée et complètement automatisé pourrait ne pas être réalisable, dû aux problèmes d'implantation. Une combinaison d'un système à boucle fermée et ouverte est recommandée, une fois le système à boucle ouverte entièrement démontré. Selon cette alternative, la ventilation serait toujours établie à partir de l'équipements diésels prévues sur chaque niveau souterrain, et des analyses de CO_2 et CO pourrait identifier les endroits sous-ventilés. La ventilation de ces endroits pourrait être accrue deux fois par quart de travail.

PHASE I

UNDERGROUND CONTAMINANTS SURVEYS

PHASE I - UNDERGROUND CONTAMINANTS SURVEYS

1. INTRODUCTION

In 1986, Brunswick Mining (BMS-M) and Noranda Technology Centre (NTC) initiated a program to improve the efficiency of underground ventilation. Brunswick is a large underground lead-zinc operation at Bathurst, New Brunswick, with considerable proven reserves. The combined electricity and propane cost for ventilating the mine was just under \$4 M in 1987.

The ventilation project, organized by BMS-M and NTC is composed of several related projects, all contributing to providing a quality working environment while reducing energy costs. One project is to automate the ventilation system to eventually provide the required amount of ventilation based on underground measurements of air quality.

The overall project encompasses four separate areas of research:

- a) establishment of practical control criteria;
- b) development and calibration of a real time ventilation model;
- c) establishment of suitable control capabilities for air regulators and fans;
- d) development of a proper data communication system.

In 1987, NTC obtained a government contract (DSS 23440-9040/01-SQ) to develop a methodology for the control of ventilation using, if possible, CO₂ as the engineering control criterion. The work is divided into two phases. Phase I requires collecting and consolidating existing data, obtaining underground pollutant profiles through a field survey at BMS-M, and verifying whether CO₂ can be used alone or in combination with other pollutants as a control parameter. Phase I covers the first overall project area outlined above, which is the establishment of practical control criteria. Phase II requires the definition of hardware, software and transmission requirements for an automated ventilation system. It covers the three last areas of research presented above.

The present report details Phase I and II work accomplished under the government contract by NTC with the help of Brunswick Mining and CANMET personnel.

2. BACKGROUND

2.1 General

Although the possibility of automating a mine ventilation system has been recognized for many years, the subject is relatively undeveloped from both the theoretical and experimental point of view.

The term "automation" generally implies that a system can operate without the intervention of a human operator to make corrections or adjustments necessary to maintain a desired condition. Since the system requires no human intervention, it is called a closed loop system as opposed to an open loop system. Although several countries developed some theoretical and experimental applications for both open and closed loop system⁽¹⁾, there is not a mine, to the author's knowledge, which has installed a complete closed loop ventilation control network. Major considerations for automation of mine ventilation include:

- a) the parameters to be controlled;
- b) the parameters to be measured;
- c) the relationships between a) and b);
- d) the locations of the controllers and measuring devices in the network.

The requirements may vary from section to section in one mine as well as from mine to mine. For example, a labour-intensive South African mine may want to control the airflow based on the amount of rock dust generated, and a British coal mine might want to use a combination of methane and dust meters to control local ventilation. For base metal mines, diesel emissions may be of more concern in a given section of the mine, whereas rock dust may be more critical in others (e.g.: crusher stations).

In a diesel-intensive mine, there are several contaminants which need to be diluted to safe concentrations, and it would be extremely capital-intensive to monitor all contaminants derived from diesel operation on a mine-wide basis. It is for this reason that a simplified control parameter or "surrogate" which would indicate that all contaminants are within acceptable levels would be highly desirable.

2.2 CO₂ as a Diesel Emission Surrogate

In the past, several researchers have looked into using CO₂ as a simple control parameter in a diesel-intensive mining operation.

The amount of CO₂ produced during the combustion of diesel fuel is directly related to the quantity of fuel burned, and the power output of the diesel engine is controlled by the amount of fuel⁽²⁾. The CO₂ concentrations in the exhaust thus vary in nearly direct proportion to the engine duty cycle and load. The CO₂ concentrations are also less affected than those of the other contaminants by improper adjustment of the fuel system, combustion chamber design, and imperfections in fuel injection nozzles. CO₂ is the only stable and non-reactive pollutant in the exhaust that is unaffected to any appreciable extent by time, emission control devices, or engine wear. Finally, CO₂ is present in the exhaust gases in the highest concentration of any of the pollutants, and very accurate and reliable instruments for its detection are commercially available.

Due to these inherent properties of CO₂, the underground concentration (when adjusted for background concentration) can be shown to be a direct measure of the local diesel exhaust concentrations resulting from the combined effects of the prevailing ventilation rate and engine power output. This relationship is illustrated in Figure 1.

Several references dealing with underground mining operations have suggested that CO₂ concentrations could allow accurate predictions of the levels of other exhaust contaminants⁽³⁻⁶⁾. The amount of CO, NO, NO₂, SO₂ and diesel soot, although related to fuel consumption, is also a function of the type of engine and its condition, the exhaust emission control devices, the duty cycle of the engine, and the operator's habits. Figure 2 shows how the CO to CO₂ ratio varies over a typical duty cycle of an engine. However, pollutant characteristic curves or plots of the individual time-weighted average (TWA) measurements of diesel pollutants versus the corresponding CO₂ concentrations were found to be linear when measured in actual underground conditions^(6,7). Figure 3 shows a plot of pollutant vs CO₂ in a dead-end drift where one LHD is operating. The relationship varies throughout the duty cycle, but the average measurements of each cycle are linear.

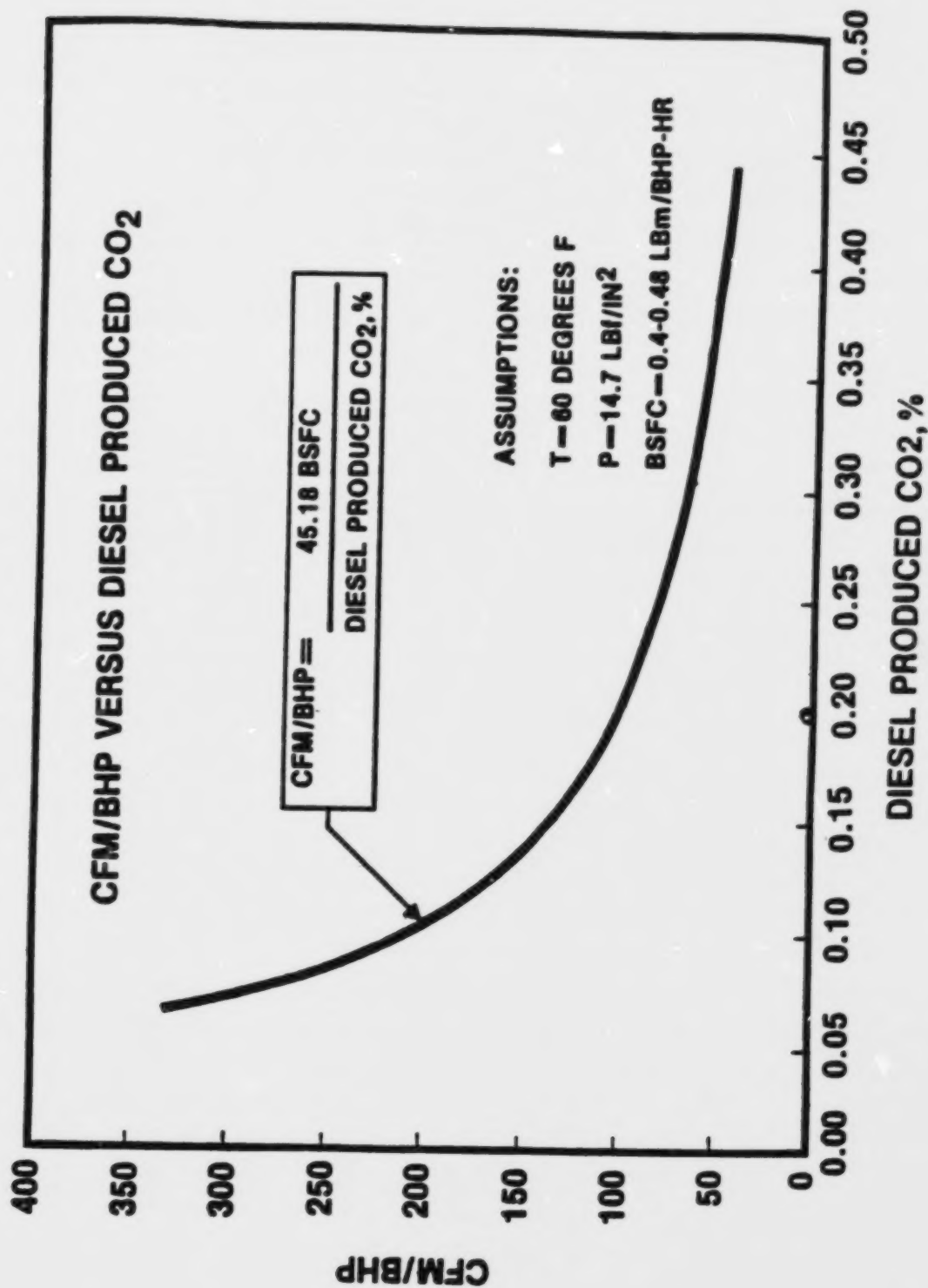


Figure 1 - CFM/BHP vs Diesel Produced CO₂
(After Johnson et al, 1986)

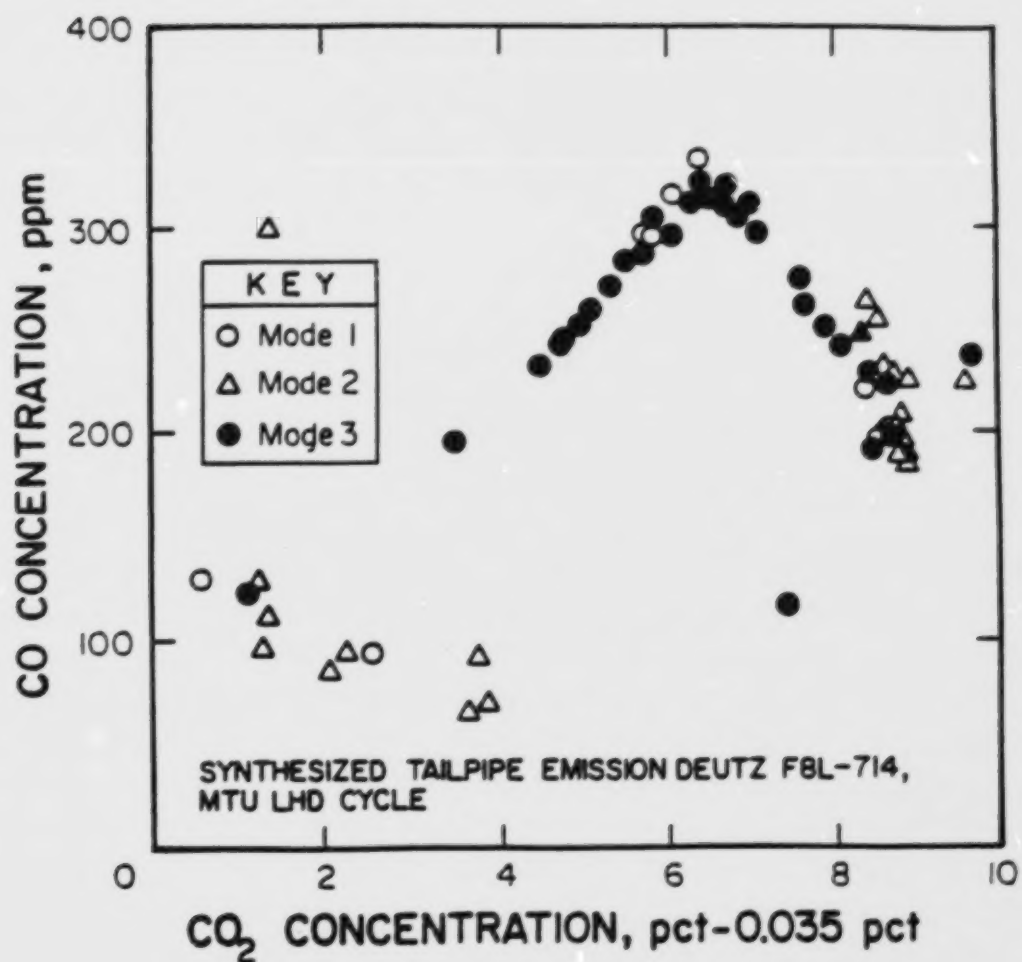


Figure 2 - Plot of Emitted CO vs CO₂
(After Daniel, 1984)

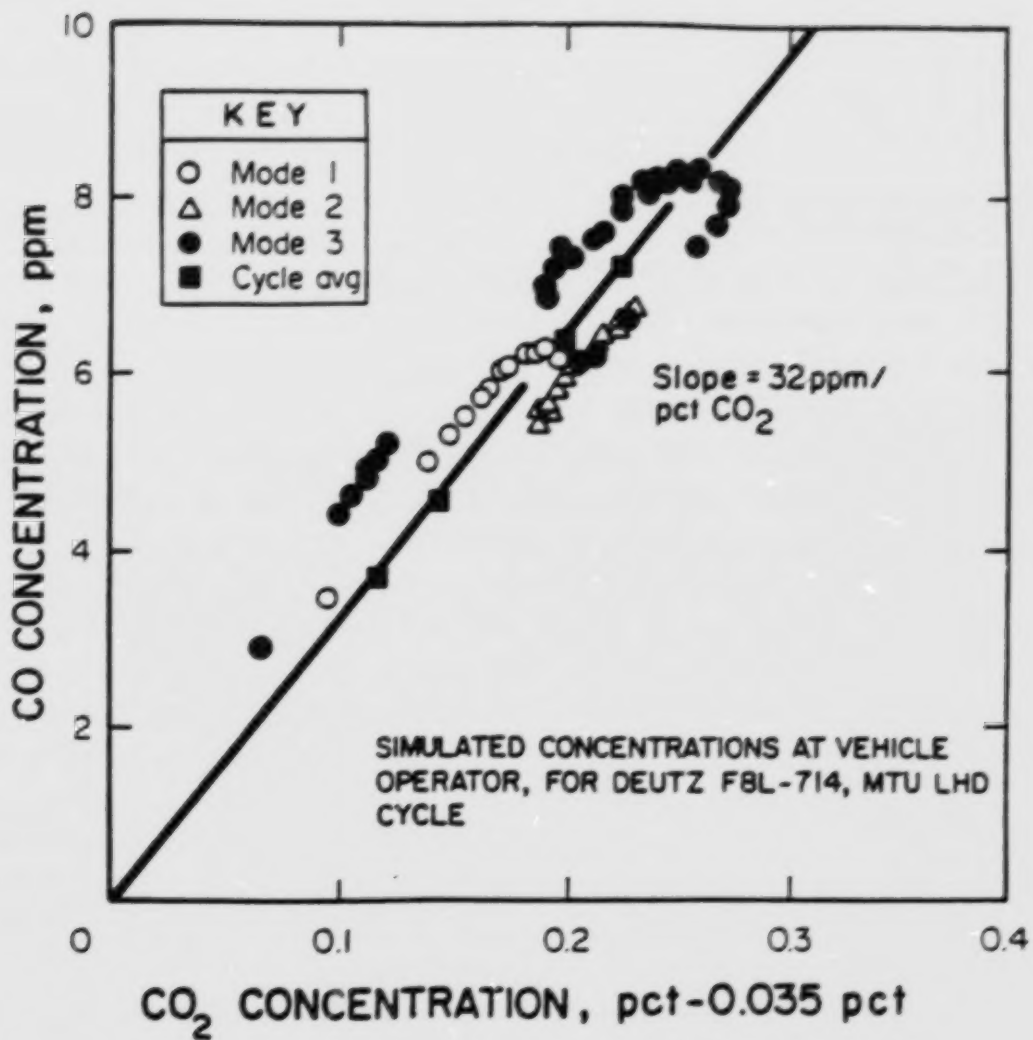


Figure 3 - Pollutant Characteristic Curve of CO vs CO₂
(After Daniel, 1984)

In 1984, Daniel proposed a new air quality monitoring methodology⁽⁷⁾ to assure a healthy environment for underground workers. It involved a new concept based, in part, on: i) the principle that CO₂ concentrations that result from diesel engine operation are directly proportional to the amount of fuel burned; ii) the concept that the other exhaust emissions are proportional to the CO₂ concentrations as defined by pollutant characteristic curves; and iii) the application of an Air Quality Index (AQI) defined in 1978 and modified in 1984 by French & Associates⁽⁸⁾, to establish a CO₂ concentration at which the other diesel pollutants are considered below harmful levels.

In 1985, Noranda Research proposed to use this concept as the basis for automating the ventilation system at Brunswick. Both Brunswick and CANMET recognized the possible benefits of this proposal, such as improved working conditions for the workers and substantial reduction in energy cost through better control, and accepted the research proposal.

3. FIRST FIELD SURVEY AT BMS-M

3.1 Objective

Earlier research involving underground CO₂ monitoring for comparison to the other diesel contaminants was carried out in dead-end drift where only one LHD was operating. Further field work was required to see if the linear relationships found between CO₂ and mine contaminants still exist in a multiple diesel section. The objective of the first field survey was, therefore, to measure CO₂ and contaminants concentrations generated in various sections of Brunswick mine where several diesel vehicles are operating on the same split of air, prepare pollutant characteristic curves for all contaminants monitored, and verify the linearity of the relationships.

3.2 Monitoring Strategy

The underground contaminants survey was undertaken over the first two weeks of November 1987. Two engineers and one technician from NTC, and two engineers and one technician from CANMET were involved in the work. Most instrumentation utilized was provided by

CANMET except for a few continuous gas monitors rented from l'Institut de Recherche en Sante et Securite du Travail (IRRSST) and Brunswick Mining's own instruments. Table I gives a list of equipment used in the study.

For the survey, it was decided to monitor the two types of mining methods employed at BMS-M. Brunswick started mining underground with a mechanized cut and fill extraction method (MCF). This method has been used to mine down to the 800 level.¹ As the mine goes deeper, open stope mining will be favoured over MCF, and the open stope method will soon account for most of the production. The MCF method uses teletram trucks, scooptrams, and loaders to extract the ore, and the open stope technique uses scooptrams to remove ore from the drawpoints. The 1000 level was chosen to represent an open stope operation and the 725 level, a room and pillar operation.

Figures 4 and 5 illustrate the set up on the 1000 level section. On the main level (Figure 4), two intake stations were installed to sample the air which was distributed to the south zone. The air, after passing through the zone, ascended through slot raises and was distributed on the south end of No.1 sub (Figure 5). An exhaust station was installed on the exit side of the zone. Station 1 was used to sample air which came from the V-5 intake (Intake 1) raise and was fairly clean except for occasional equipment moving in and out of the garage and parking area. Station 2 was used to sample reused air which came from the ramp, but the volume entering the zone was small compared to Intake 1 volume. The exhaust station was therefore measuring contaminant concentrations generated, for the most part, in the south end, including the operation of diesel and drilling equipment.

Figures 6, 7 and 8 illustrate the set-up in the 725 level north end. On the sill level (Figure 6), two stations were installed. Station 1, an intake, sampled air which came almost entirely from boreholes connected to 850 level. The contaminated air volume passing by Station 1 split in two with about 50% flowing into the 725 north end, and 50% short-circuited to the V-4 exhaust. Station 2 sampled the exhaust air which left the north end through the V-4 exhaust raise. The next two figures (Figures 7 and 8) illustrate the other intakes which provided air to the 725

1. All levels are in meters.

TABLE I
INSTRUMENT LIST

CONTINUOUS MONITORING

3	-	CO ₂ Fuji Infrared Analyzers
2	-	SO ₂ Interscan Electrochemical Analyzers
3	-	CO Ecolyzer 7230 Electrochemical Analyzers
3	-	Dust MIE Inst. Miniram Light Scattering Analyzer
4	-	Data Loggers, Grant Squirrel, 4 Channel, 16 k Memory

TIME WEIGHTED AVERAGE MONITORING

<u>CO/CO₂</u>	4	-	Wood Sampling Cases
	4	-	22 L Snout-type 5-Layer Bags
	4	-	PI25 Constant-Flow Sampling Pumps
		-	Long-duration Draeger Detector Pumps
<u>NO/NO₂</u>	200	-	Passive Palmes Personnel Samplers
		-	Long-duration Draeger Detector Tubes
<u>Dust</u>	8	-	P4000 Constant Flow Pump, Charger & Filter Holder Assembly
	8	-	Box 99 Respirable Dust Lapel Samplers
	60	-	Gelman 61652 A/E Glass Fiber Filters
<u>Other</u>	4	-	Draeger Polymeter, Battery-Powered Peristaltic Pump for Long-Duration Detector Tubes
		-	Calibration Gases for Zeroing and Spanning of Continuous Monitors

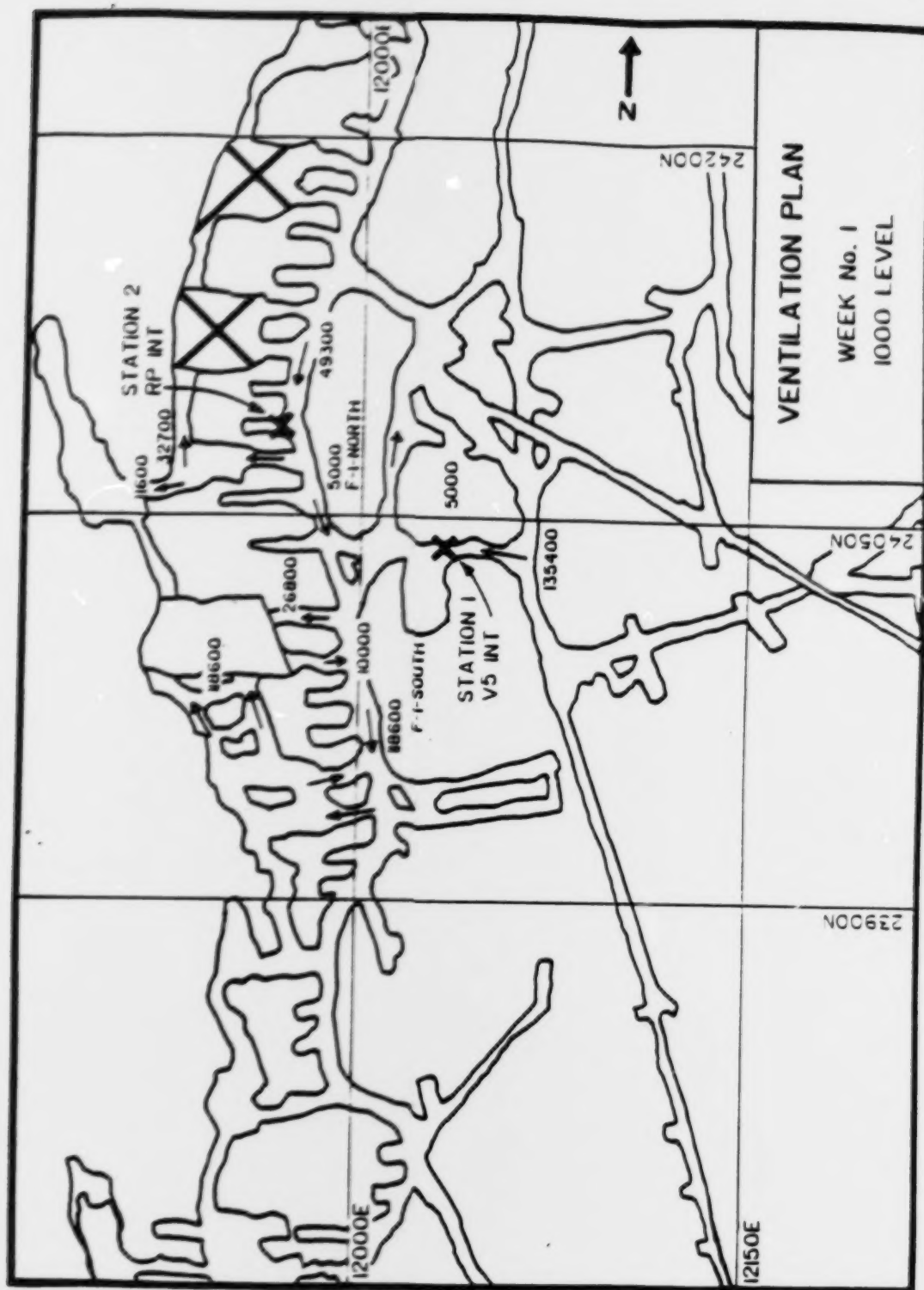


Figure 4 - Ventilation Plan, 1000 Level

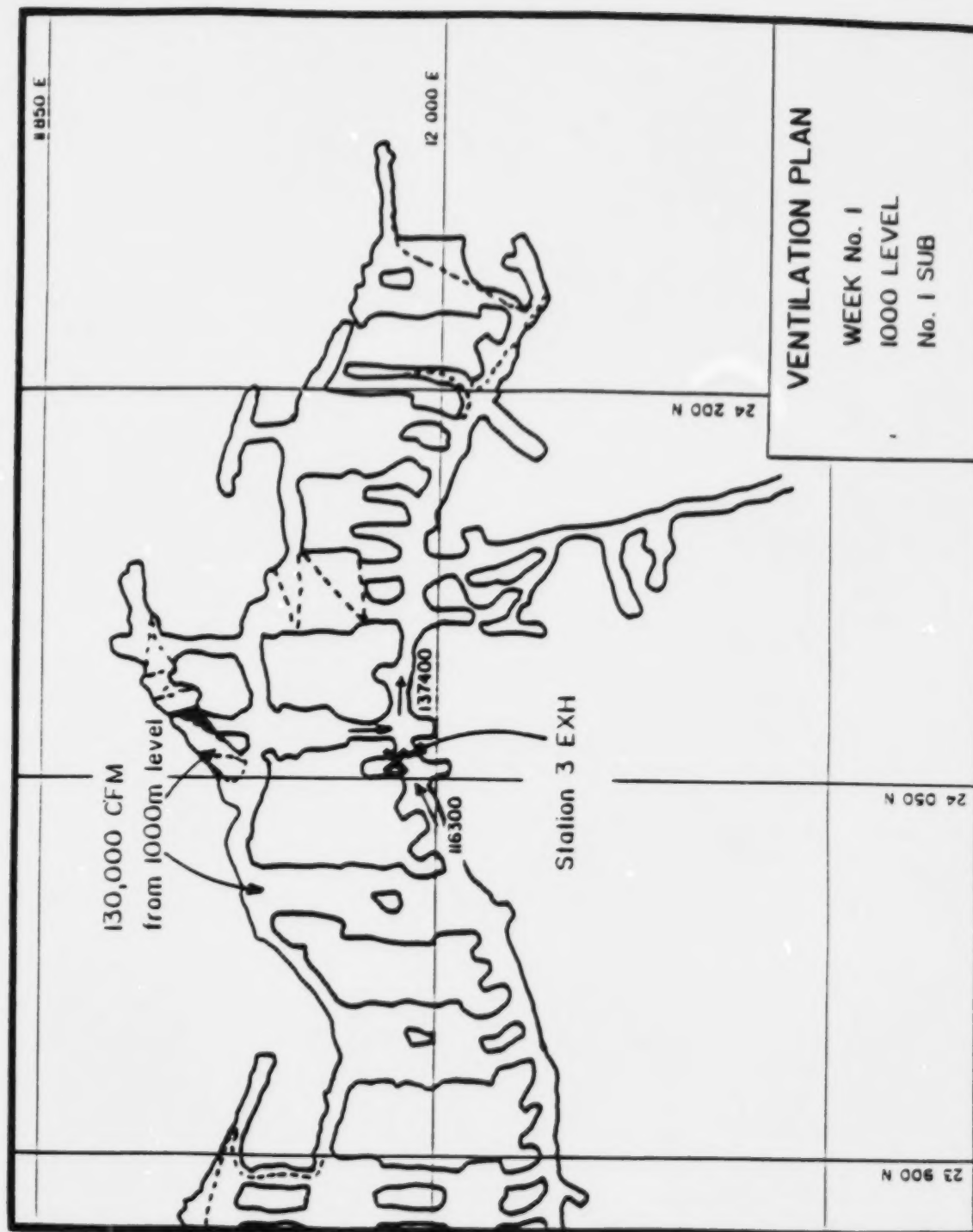


Figure 5 - Ventilation Plan, 1000 Level, No. 1 Sub

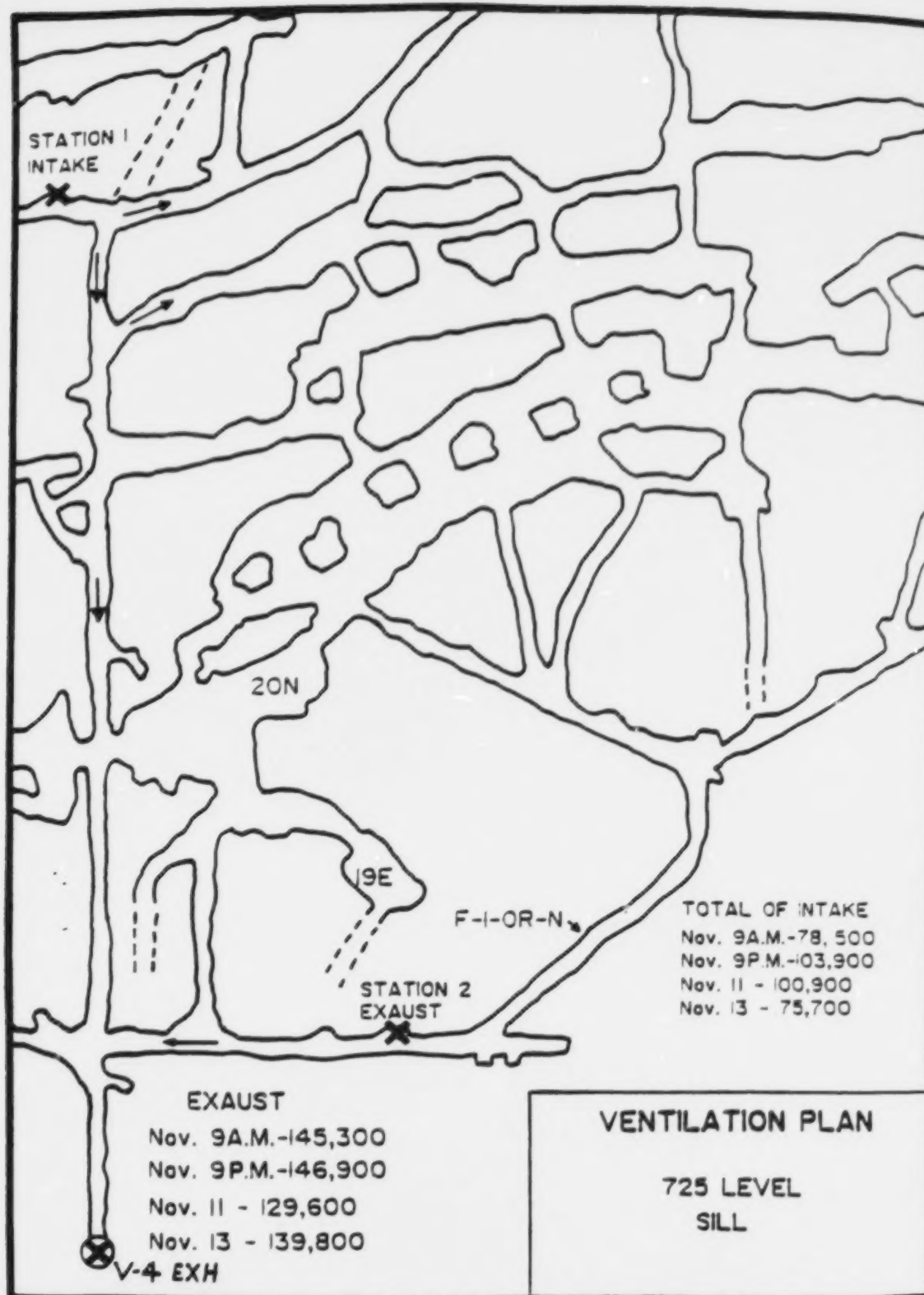


Figure 6 - Ventilation Plan, 725 Level Sill

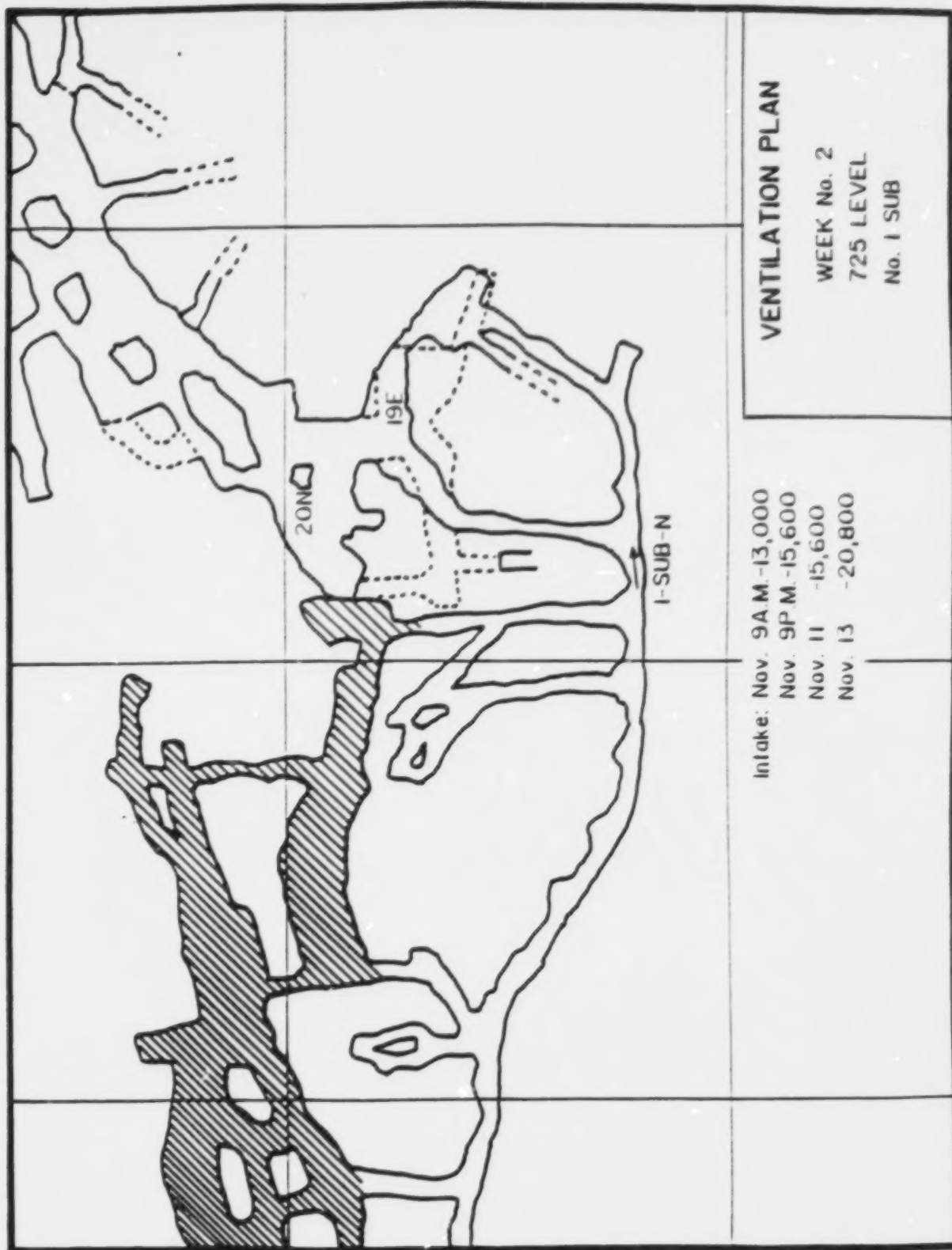


Figure 7 - Ventilation Plan, 725 Level, No. 1 Sub

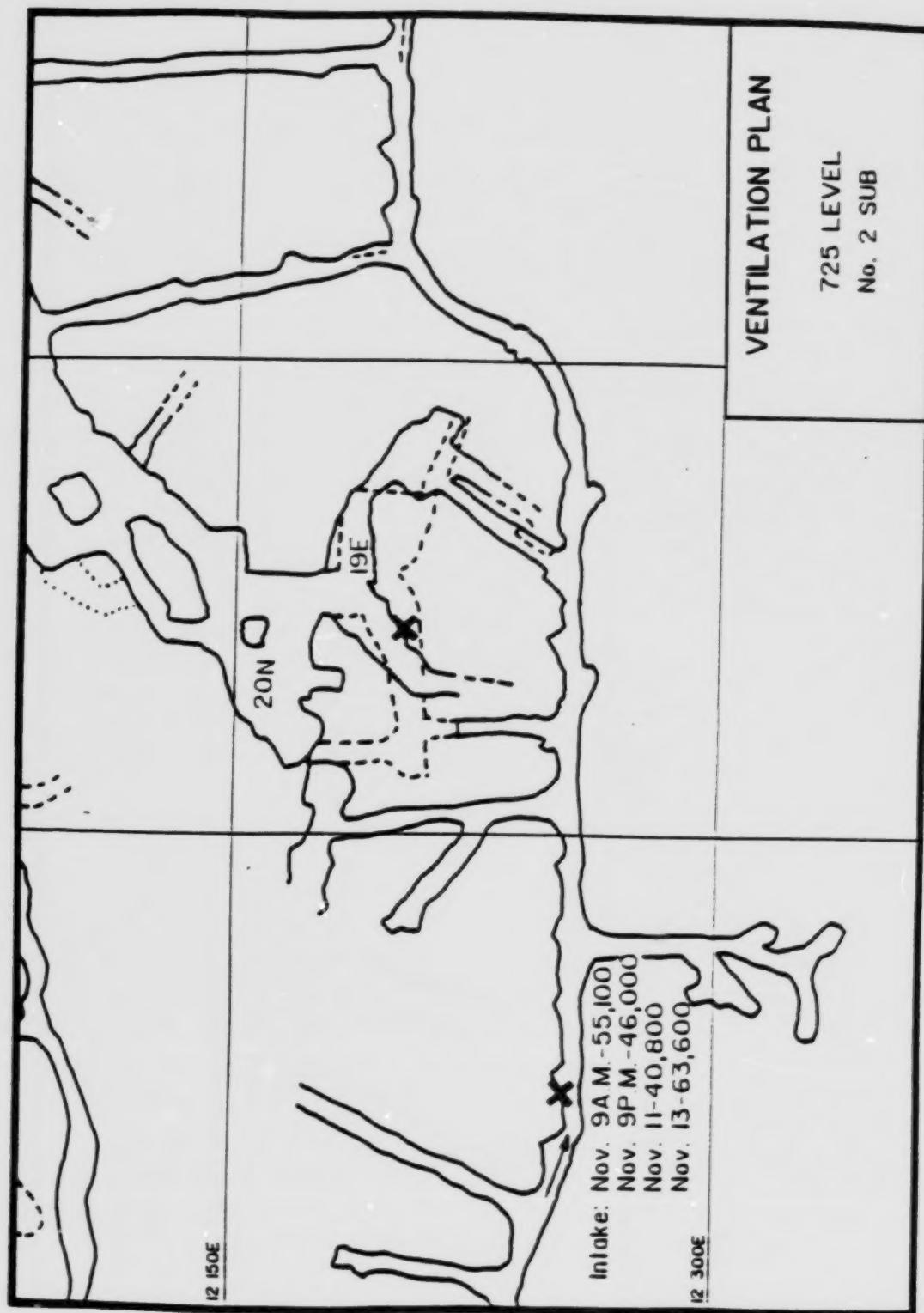


Figure 8 - Ventilation Plan, 725 Level, No. 2 Sub

north end. The air came out of the V-5 intake, partly flowed to the north end through No. 1 sub (Figure 7), and the remaining portion flowed in the north end via the ramp connecting No. 1 and 2 subs. The air, which flowed into the section through the subs, was clean except for infrequent diesel equipment entering the ramp, and corresponded to approximately 65-70% of the 725 north end ventilation. Because this air was fairly clean, no monitoring stations were installed in the sub intakes, and it was assumed that the one station at the V-5 represented the sole intake to the north end stoping block.

The volumes provided to the various sections, which are indicated in Figures 4-8 were measured daily with the use of velometers by mine ventilation technicians.

3.3 Presentation of Results

On the first week of the survey, the instruments were installed on 1000 level. Some trouble was encountered initially with instrumentation, and data for the first day (3 November) were removed from the results. The instruments were moved to the 725 level for the second week, and data was recorded for three days (10-12 November). Each day, all gas analyzers were calibrated at the beginning and mid-shift with zero and span gas.

All the continuous monitoring results of the contaminants were transferred to a Lotus data base at NTC where they could be manipulated at will. Graphs of the contaminants versus time were first plotted to compare the trends. Figures 9, 10 and 11 show three days of monitoring results (1000 level and 725 level). It can be observed from the figures that all gases have much the same concentration trends over time, which suggests that CO_2 can be used as a surrogate of the gas contaminants. To study this possibility in more detail, the gas results were compared individually to CO_2 .

To compare the data, the individual contaminants were plotted against CO_2 and a linear regression applied. In most cases where the instruments were calibrated in mid-shift, two symbols were used to represent A.M. data and P.M. data. A second graph was then generated from the same data base by plotting 15-minute averages. Linear regression was also calculated for the 15-minute average results. For the dates for which good intake continuous measurements were taken (4, 11 and 12 November), the exhaust concentrations were corrected for intake pollution and the data analyzed in the same way.

NOVEMBER 4TH RESULTS

EXHAUST (NO. 1 SUB, 1000 LEVEL)

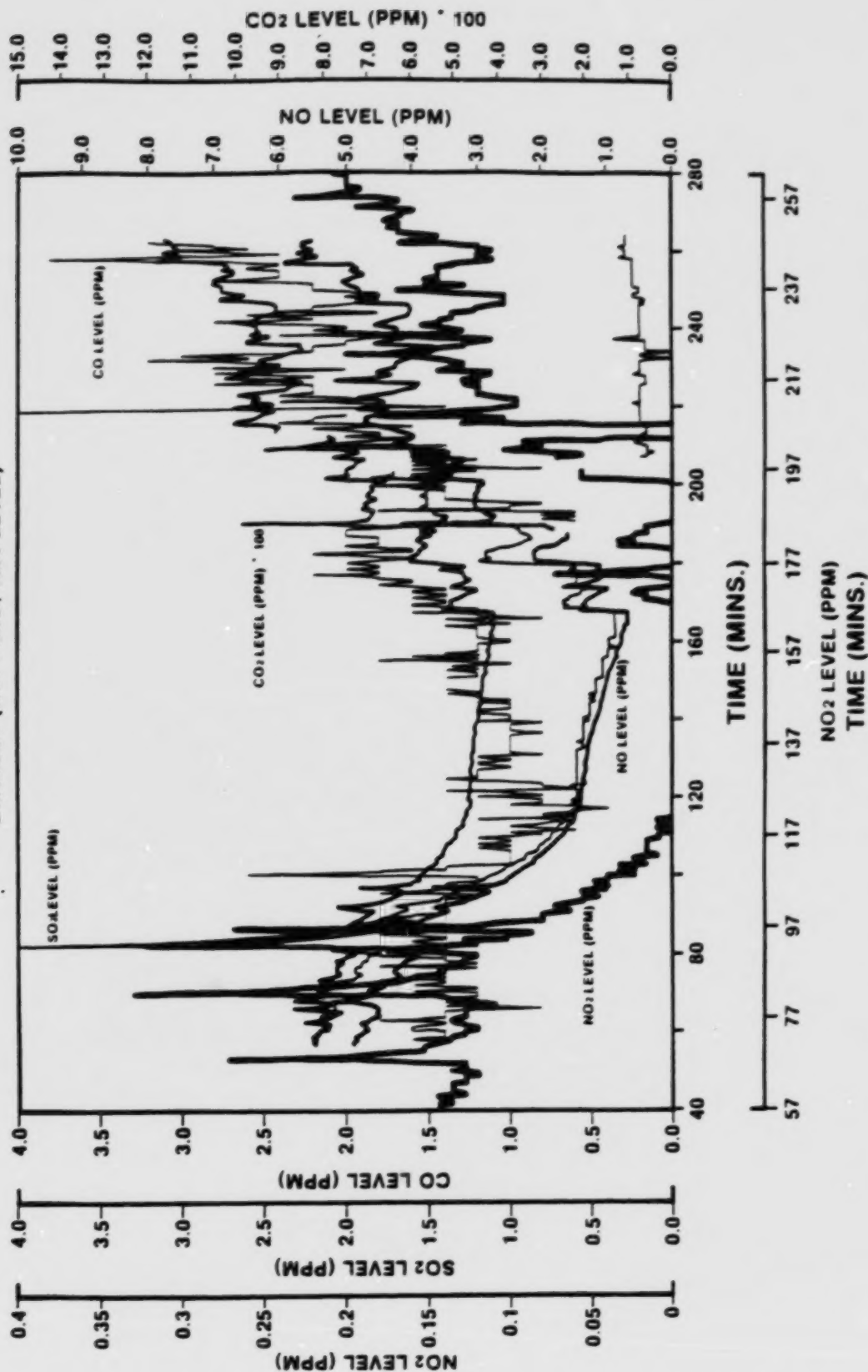


Figure 9 - Graph of Contaminants vs Time, 4 November 1987

NOVEMBER 5TH RESULTS

EXHAUST (NO. 1 SUB, 1000 LEVEL)

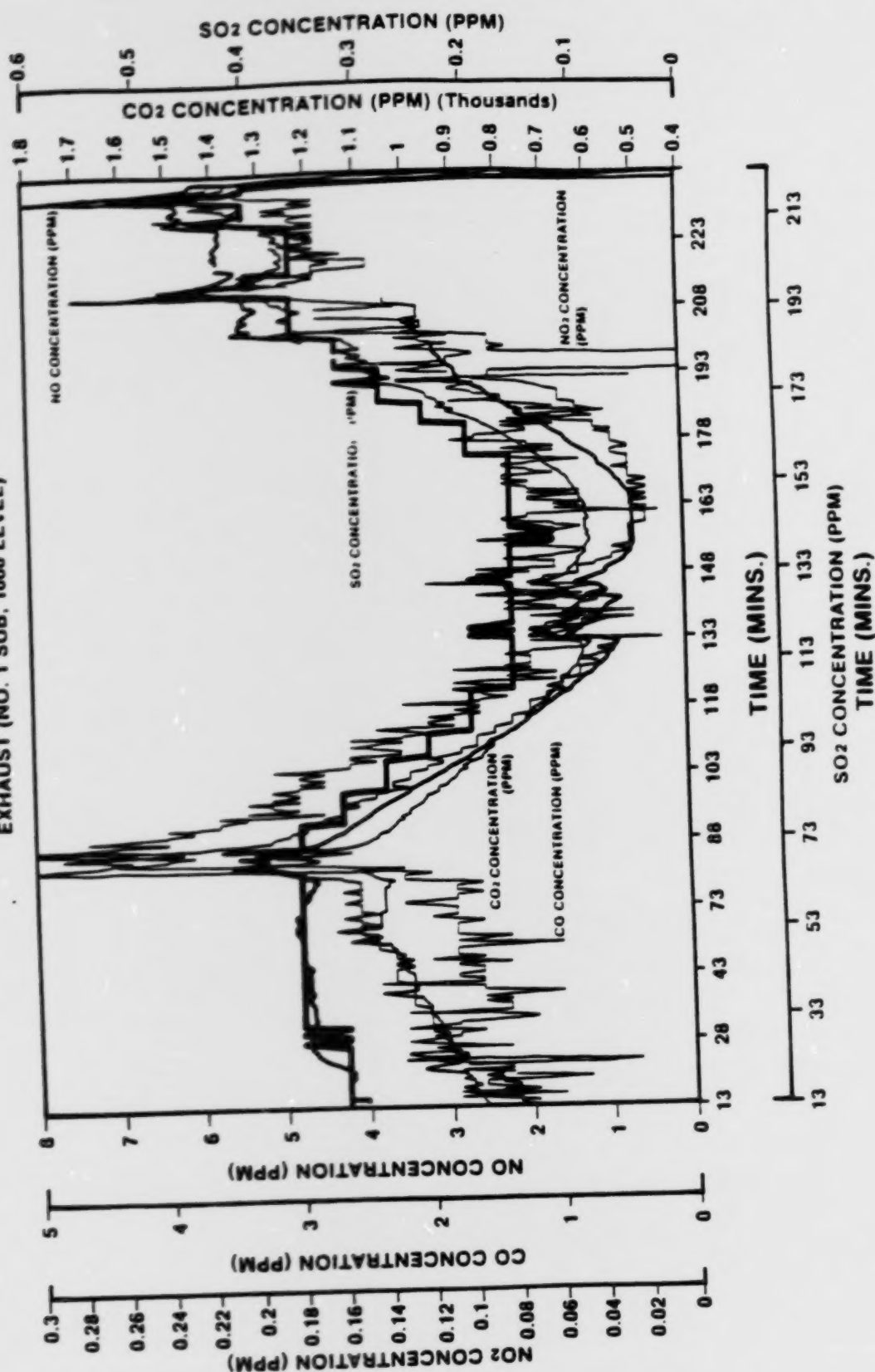


Figure 10 - Graph of Contaminants vs Time, 5 November 1987

NOVEMBER 11TH RESULTS

EXHAUST (2350 M.O.Z.)

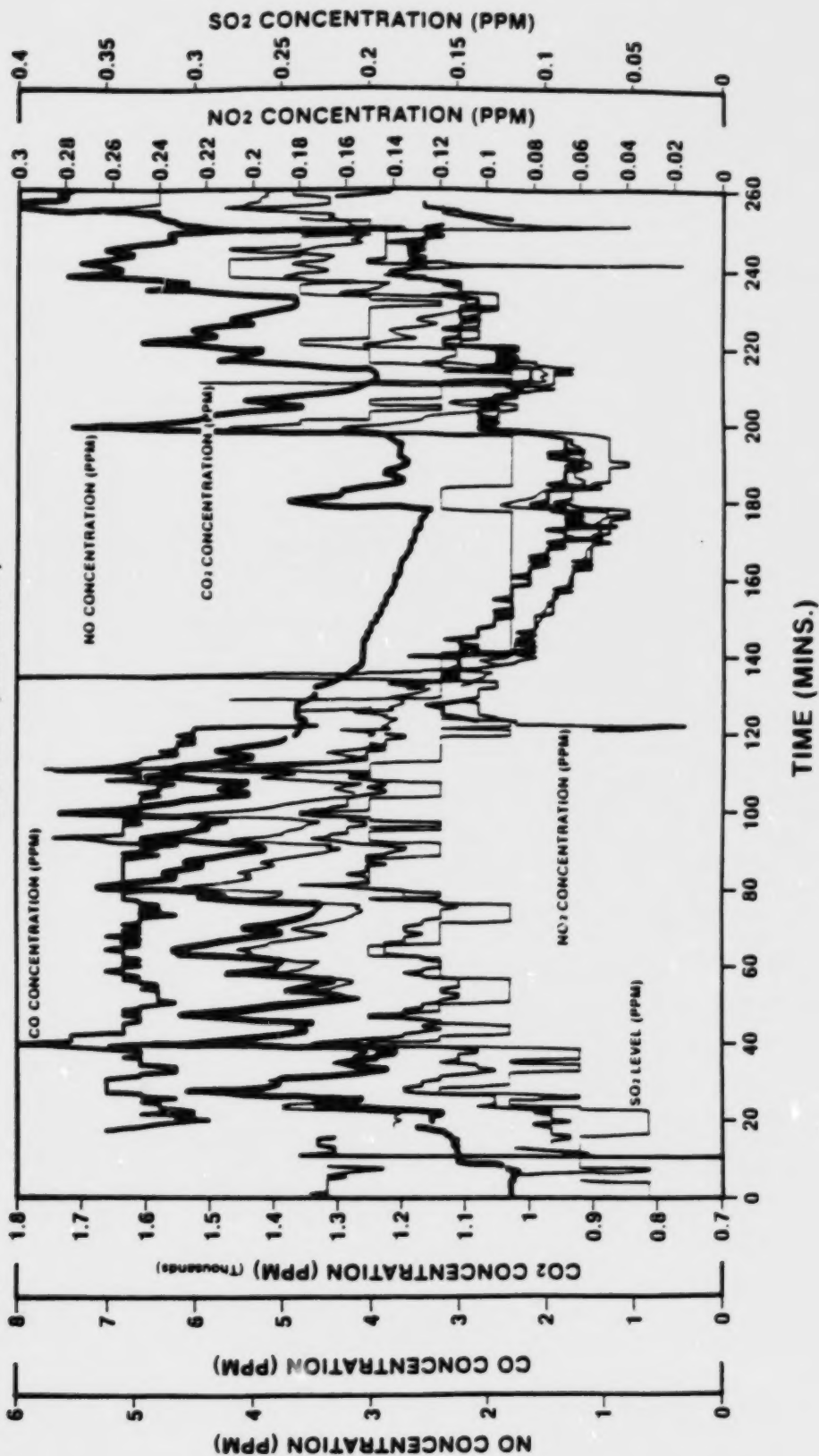


Figure 11 - Graph of Contaminants vs Time, 11 November 1987

All the graphs are presented in Appendix A, Parts A-D. Table II gives the results of all regressions for gaseous contaminants.

During the survey, simultaneous TWA samples of all contaminants and respirable dust were taken. Also, TWA samples were taken directly on diesel equipment operating in the sections.

Table III gives a detailed analysis of the time-weighted average results including RCD and on-board measurements. The table is divided into monitoring dates and location. For each date and location, there are three data columns. The first gives a list of contaminant concentrations for that date and location, the second, the ratio of the contaminants to their TLV (D/TLV), and the third, the ratio of CO₂ to the specific pollutant. For respirable combustible dust (RCD), these are the only results available, as it was not possible to make continuous measurements. Dust readings were recorded with the Miniram monitors during the survey, but due to a lack of consistency in the recording and difficulty with the calibration procedure, the data are not included in the report.

3.4 Discussion of Results

3.4.1 Continuous Gas Results

By referring to Table II, it can be seen that the nitric oxide to CO₂ correlations are excellent with most over 0.75. The averaged data always improve the correlations. This was expected for two reasons. Firstly, the CO₂ analyzer is a more sensitive instrument than the NO and averages cut out the noise. Secondly, it was mentioned in the background section of this report that NO is related to other factors besides the power output of the engine. Therefore, during a duty cycle, the NO (as will all other contaminants) to CO₂ ratio will vary. The duty cycle varied between 5 and 15 minutes on the sections monitored, and taking 15-minute averages acted to smooth out these variations within a cycle. Some care must be taken in interpreting the average correlations. By averaging the results, we reduce considerably the number of points used in the regression, and the statistical degree of freedom is very small compared to non-averaged results.

TABLE 11
LINEAR REGRESSION ANALYSIS

		NO vs CO ₂		CO vs CO ₂		NO ₂ vs CO ₂		SO ₂ vs CO ₂	
		Correlation	No. of Points	Correlation	No. of Points	Correlation	No. of Points	Correlation	No. of Points
November 5									
Total Exhaust	A.M. P.M.	0.95 0.66	125 212	0.10 0.15	125 212	0.7 0.54	125 212	0.84 0.34	125 212
Corrected Exhaust	A.M. P.M.	0.95 0.69	120 207	0.12 0.46	120 207	0.80 0.75	120 207	M/A M/A	120 207
Average Exhaust	A.M. P.M.	0.97 0.95	5 9	0.30 0.64	5 9	0.78 0.91	5 9	0.98 0.96	5 9
Average Corrected	A.M. P.M.	0.96 0.97	5 9	0.38 0.68	5 9	0.68 0.98	5 9	M/A M/A	5 9
November 5									
Total Exhaust	All Data	0.87	329	0.50	329	0.74	329	0.86	329
Average Exhaust	All Data	0.89	14	0.61	14	0.78	14	0.89	14
November 6									
Total Exhaust	A.M. P.M.	0.98 0.84	112 91	All Data: 0.74	203	0.51	203	0.72	203
Average Exhaust	A.M. P.M.	0.75 0.91	7 99	All Data: 0.89	8	0.55	8	0.96	8
November 10									
Total Exhaust	A.M. P.M.	0.75 0.96	7 8	0.66 0.76	191 99	M/A M/A	191 99	0.72 0.89	191 99
Average Exhaust	A.M. P.M.	0.75 0.96	7 8	0.83 0.75	7 8	M/A M/A	7 8	0.43 0.98	7 8
November 11									
Total Exhaust	A.M. P.M.	0.63 0.82	208 256	0.52 0.69	208 256	0.39 0.51	208 256	0.49 0.66	208 256
Corrected Exhaust	A.M. P.M.	0.78 0.76	208 238	0.37 0.58	208 238	0.50 0.53	208 238	M/A M/A	208 238
Average Exhaust	A.M. P.M.	0.314 0.90	7 9	0.52 0.85	7 9	0.35 0.93	7 9	0.31 0.85	7 9
Average Corrected	A.M. P.M.	M/A 0.77	M/A 9	M/A 0.71	M/A 9	M/A 0.83	M/A 9	M/A M/A	M/A 9
November 12									
Total Exhaust	A.M. P.M.	0.64 0.63	M/A M/A	0.102 0.38	2.05 273	0.076 0.114	2.05 273	0.02 0.62	2.05 273
Corrected Exhaust	A.M. P.M.	0.46 0.40	205 273	0.167 0.23	205 258	0.02 0.22	205 258	M/A M/A	205 258
Average Exhaust	A.M. P.M.	0.57	16	0.55	12	0.89	12	0.81	12
Average Corrected	A.M. P.M.	0.73	13	0.75	12	0.81	12	M/A	12

TABLE III
TWA RESULTS

1000 METER LEVEL	BP INT		Exhaust	
	TLV 2.	Date 3.	B/TLV	CO ₂ /Gas
November 4				
CO	50	1.00	0.02	620.00
CO ₂	5000	620.00	0.12	1.00
NO	25	2.67	0.11	232.21
NO ₂	3	0.32	0.11	1937.50
RCD ¹ .	2	0.40	0.20	1550.00
Scoop VL 167				
Scoop VL 176				
November 5				
CO	50	9.00 ⁴	0.18	94.44
CO ₂	5000	850.00	0.17	1.00
NO	25	4.00	0.16	212.50
NO ₂	3	0.39	0.13	2179.49
RCD	2	0.73	0.37	1164.38
Drill (34-1)				
Scoop 174				
November 6				
CO	50	0.00	0.00	N/A
CO ₂	5000	950.00	0.19	1.00
NO	25	4.48	0.18	212.05
NO ₂	3	0.50	0.17	1900.00
RCD	2	0.75	0.38	1266.67

1. RCD = respirable combustible dust (mg/m³)
2. Threshold Limit Value (ppm) except in the case of RCD where it is an ACGIH recommended value
3. ppm except for RCD
4. Abnormal CO concentration which is probably due to calibration error

TABLE III (Con'd)

TMA RESULTS

TZS METER LEVEL	V-5 Intake			Exhaust			Diesel Unit 1			Diesel Unit 2		
	TLV 2.	Date 3.	D/TLV	CO ₂ /Gas	Date	D/TLV	CO ₂ /Gas	Date	D/TLV	Date	D/TLV	CO ₂ /Gas
<u>November 9</u>												
CO	50	M/A	0.00	M/A	2.00	0.04	500.00	0.50	0.01	1.00	0.02	450.00
CO ₂	5000	M/A	0.00	M/A	1000.00	0.20	1.00	550.00	0.11	450.00	0.09	1.00
NO	25	0.07	0.00	0.00	3.22	0.13	310.56	0.56	0.02	3.20	0.13	140.63
NO ₂	3	0.27	0.09	0.00	0.54	0.18	1851.85	0.16	0.05	0.39	0.13	1153.85
RCD 1.	2	0.44	0.22	0.00	0.39	0.20	2564.10	0.57	0.29	0.54	0.27	833.33
<u>November 10</u>												
CO	50	0.00	0.00	M/A	1.50	0.03	666.67	1.00	0.02	3.00	0.06	266.67
CO ₂	5000	350.00	0.07	1.00	1000.00	0.20	1.00	450.00	0.09	800.00	0.16	1.00
NO	25	0.00	0.00	M/A	4.17	0.17	239.81	4.52	0.18	3.56	0.14	224.72
NO ₂	3	0.22	0.07	1590.91	0.35	0.12	2857.14	0.53	0.18	0.39	0.13	2051.28
RCD	2	0.25	0.13	1400.00	0.31	0.16	3225.81	0.87	0.44	0.36	0.18	222.22
<u>November 11</u>												
CO	50	0.00	0.00	M/A	3.00	0.06	375.00	M/A	0.00	2.50	0.05	366.80
CO ₂	5000	350.00	0.07	1.00	1125.00	0.23	1.00	M/A	0.00	850.00	0.17	1.00
NO	25	0.11	0.00	3181.82	3.44	0.14	327.03	4.38	0.18	2.94	0.12	310.20
NO ₂	3	0.06	0.02	5833.33	0.31	0.10	3629.03	0.10	0.03	0.45	0.15	2026.67
RCD	2	0.10	0.05	3500.00	0.29	0.15	3879.31	0.58	0.29	0.18	0.09	5066.67
<u>November 12</u>												
CO	50	0.00	0.00	M/A	2.00	0.04	437.50	M/A	0.00	2.00	0.04	399.00
CO ₂	5000	300.00	0.06	1.00	875.00	0.18	1.00	M/A	0.00	900.00	0.18	1.00
NO	25	0.12	0.00	2500.00	2.08	0.08	420.67	4.11	0.16	2.78	0.11	287.05
NO ₂	3	0.02	0.01	15000.00	0.39	0.13	2243.59	0.51	0.17	0.42	0.14	1900.00
RCD	2	0.22	0.11	1363.64	0.22	0.11	3977.27	0.53	0.27	0.39	0.20	2046.15

1. RCD = respirable combustible dust (mg/m³)

2. Threshold Limit Value (ppm) except in the case of RCD where it is an ACGIH recommended value

3. ppm except for RCD

For carbon monoxide, the characteristic curves are not as linear as NO (Appendix A, Part B). All the equipment operating on 725 and 1000 levels was equipped with catalytic converters which, when functioning properly, will remove as much as 70% of CO generated. This considerably reduces the health threat posed by carbon monoxide in these sections, but may also reduce the linearity of the relationship between CO and CO₂ because the efficiency of the converter will vary with engine load. Table II, Part B, presents the regression data for CO₂ and CO. As with NO, regression improves when 15 min. averages are used. Some of the correlations are very low (4 and 12 November) due to the low ambient concentrations and the effect of catalytic converters.

The portion of NO_x emitted in the form of NO₂ by the diesel engine is usually insignificant, but the conversion of NO to NO₂ in the mine atmosphere can contribute significantly to the total NO₂ exposure in a mine. NO₂ and NO found underground are generally proportional with NO being 10 times or more the level of NO₂. NO₂ is a very unstable gas and tends to absorb on various substances found in the mine. Its low concentration (under 1 ppm) and reactive nature make it hard to compare with CO₂.

Referring to Table II, it can be observed that the regression analysis for CO₂ and NO₂ vary widely with coefficients of regression between 0.02 to 0.98.

The quantity of SO₂ emitted in diesel exhaust is directly related to the sulphur content of the fuel. Mines using a fuel containing less than 0.15% sulphur will usually not have critical SO₂ concentrations underground. SO₂, like NO₂, is very reactive and will adsorb onto diesel soot and with water convert to H₂SO₄, which makes its detection very difficult. In addition, SO₂ electrochemical detectors, which can detect below 1 ppm are unreliable and sensitive to other gases. The instruments used for the survey were two Interscan electrochemical detectors. Difficulty was experienced in calibrating these instruments. Table II shows the correlation for SO₂ and CO₂ graphics. On the average, correlation is better than 0.7, which is very good. The 4 November results are offset by a large factor with an average concentration over 2 ppm. The afternoon calibration brought the readings back to normal which is below 0.5 ppm. The SO₂ detector is much less sensitive to changes in concentration than the CO₂ detector, and this is why the concentration points move up in step form (see Appendix A, Part D). Fifteen minutes averages improve the results substantially as they remove the step distribution from the regression. Although the absolute level of SO₂ underground could not be validated due to instrument limitations, the results do indicate a linear relationship between CO₂ and SO₂.

3.4.2 Correction to Exhaust Data

To have exact data on contaminants generated in 725 level and 1000 level, the intake pollution concentration should normally be removed from the exhaust concentration. Because of various instrument malfunctions during the survey, several days of intake monitoring could not be used in the analyses.

However, correction could be applied to November 4, 11 and 12 data (Table II). The results generally improved except in cases where the initial correlation was poor.

3.4.3 TWA Measurements

From the second column of Table III (TLV), it can be seen that the respirable combustible dust (RCD) is the most critical of the contaminants. However, its concentration was rarely more than 20% of TLV with a few locations reading 35%. In general, all contaminants were between 10 and 20% of TLV.

The TWA measurements on diesel units were very acceptable on 725 level. They were on the average about 20% of TLV except for the RCD which reached 0.87 mg/m^3 (44%) on one unit. The diesel units monitored were loaders, teletrams and scoops. On 1000 level, the stagnant air in the draw point, which is associated to open stoping mining, increased considerably the level of pollutants at which the scoop operator was exposed during the shift. On 5 November, Scoop VL 167 and Scoop VL 176 were exposed to over 1000 ppm of CO_2 . The operator of Scoop VL 167 was exposed to as much as 15 ppm NO (60% of TLV). Data for Scoop VL 174 are much lower. However, it was idle for most of the shift.

3.4.4 Reliability of Instrumentation

To achieve the objective of our survey, we had to rely very heavily on instrumentation. The data presented in this report are only as good as the output from the instruments, and it is therefore important to assess the accuracy of instrumentation.

For TWA measurements, passive-type Palmes samplers were used to collect NO_2 and NO_x samples, and bag samples with subsequent analysis by Ecolyser Instruments were also used to measure CO and CO_2 . Pump samplers were also used to measure total respirable dust and RCD.

Palmes samplers measure NO_2 and NO_x by converting NO_x to NO_2 using a chromic acid disk and absorbing the NO_2 with a reagent coated stainless steel screen. The NO_2 collected is then dissolved and determined colorimetrically. These dosimeters were found to give repeatable readings within ± 0.05 ppm when two were placed side by side⁽⁹⁾.

The TWA for CO and CO_2 were measured by sampling ambient air continuously for the duration of the shift in a five-layer 22 L bag, which will not allow any permeation of gases, will not chemically interact with gases, and will not absorb or adsorb to any degree. The sample was then analyzed with an Ecolyser 2106 electrochemical analyzer for CO and the Fuji ZFP5 infrared analyzer for CO_2 . Both analyzers are calibrated with zero and span gas just prior to the analysis. A paper by Johnson et al⁽¹⁰⁾ in 1980 showed that the Ecolyser 6000 produced similar TWA values as a Beckman 315B NDIR instrument. The model 6000 uses similar technology to the 2106 and differs only in its concentration range. It would be expected that the 2106 be given a similar accuracy when compared with a Beckman infrared instrument or other reliable infrared analyzer (such as Horiba's) if properly calibrated immediately before the analysis and also if the concentration is more than 5% of the full range. For smaller than 5% of full range (~ 2.5 PPM CO), it may be difficult to have a reliable reading due to the reduced sensitivity of the cell at this low concentration. The Fuji analyzer used to measure CO_2 will produce a very accurate readings because it has an accuracy of 5% of full 0-2000 ppm scale and by 10% of indication on 0-5000 ppm range, and the CO_2 level in the bag always over 250 PPM (ambient concentration), which is over 17% of full scale.

For the dust TWA samples, the accuracy of measurements can be severely affected by the changes in the moisture content of the filters, even if a manostat box to control humidity is used because the quantities of particulate matter collected are very small. In this case, for the analysis of the sample collected, the filters were dried at 120°C . To worsen matters, dust is not always well dispersed in the underground mine air, and two samplers placed side by side will often provide widely different results. Nonetheless, gravimetric point sampling is the best available method.

For instantaneous monitoring of dust particles, Brunswick Mining uses Miniram light scattering monitors. Unfortunately, the Miniram monitors were not equipped with the data loggers which are required for continuous sampling, and only point measurements could be made.

For continuous monitoring of the CO, NO and NO₂, Ecolyser electrochemical analyzers were used. In the mine application, accuracy, repeatability and interference from other gases were the limiting factors. Studies by the Research Triangle and Michigan Tech. University⁽¹⁰⁾ show that these cells can zero and span drift by over 2% of full scale in 24 hours which, when measuring very low concentrations, can account for errors of over 100%. Sensors have also been found to drift rapidly and dramatically in a very short period of time. The only way to minimize this problem is to calibrate frequently. The SO₂ continuous monitor also uses an electrochemical cell and has the same disadvantages. Additionally, SO₂ is very sensitive to other diesel contaminants and is present in the mine in lower concentrations than any other gases.

For CO₂ continuous monitoring, Fuji-infrared analyzers were used. These instruments are not characterized by the severe drift inherent to electrochemical cells and require less frequent calibration. The concentrations measured were also fairly high (~100-500 ppm) and a 2% drift over full scale would have had a small effect on actual measurement. The response time of the instruments is approximately 10 sec. to reach 90% of measurement, whereas all electrochemical cells will take around 45 to 60 sec. This is an important technical difference, since in a mine area where contaminant levels change rapidly and significantly, such as in a haulageway, it will create a response lag between sensors and produce inaccurate correlations. Another factor which could be of importance is the sensitivity of the instruments. At the levels likely to be measured underground, the CO₂ will be very sensitive to small incremental changes in concentration, and low concentration gas sensors like SO₂ and NO₂ will not respond to these changes.

To continuously record the data generated by the sensors, analog recorders or data loggers were used. The loggers have a resolution of 0.4% of full scale (8 bits capacity), four recording channels and a memory of 16 K or 16000 data points. By setting the sampling time to 30-second intervals, eight hours of recording time could be obtained. The logger prompted the sensors every 30 seconds, producing an instantaneous reading.

As highlighted above, the electrochemical cells used for continuous underground monitoring experience drift. It is very important to illustrate how the instrument's drift can affect the correlation of CO₂ concentration as compared to the other contaminants (NO, NO₂, CO, SO₂). Figure 12 shows the exhaust correlation between NO and CO₂ on 12 November. Twenty minutes before the end of the shift, the response of the NO cell started to drift upward rapidly, and before the instruments were disconnected, the NO concentration measured had moved from 3.3 ppm to 4.7 ppm for a CO₂ concentration of 1000 ppm. If the last twenty minutes of recording is removed from the data base, the regression coefficient changes from 0.63 to 0.94 and the same correction on the 15-minute averaged results changes its regression coefficient changes its regression coefficient from .57 to 1.0, a perfect line!

The next figure (Figure 13), NO vs CO₂ for 6 November, shows another interesting characteristic of electrochemical response drift. In the morning, the CO₂ concentration gradually decreased as equipment activity slowed down. Similarly, the NO decreased but drift of the cell accelerated the decrease in concentration. The NO analyzer was then calibrated, the points lined up perfectly with the early morning points. In mid-afternoon, there was a large increase in diesel activity and, this time, the instrument drifted upward with the increase in concentration. The instruments would appear to drift downward with lowering concentration and upward with rising concentration.

To verify the validity of the results, continuous instrument data can be averaged over the shift and compared with the TWA. This approach is not entirely correct because several times during the survey, the continuous instruments were started over half an hour after the TWA instruments. This can have a significant effect on the average since the recording was usually started at 9:30 or 10:00 A.M., at which time, the diesel equipment is used the most extensively and concentrations are the highest. Table IV shows the results of the comparison. Only the exhaust results are used because the concentrations in the intake are much lower and introduce greater inaccuracies. The CO₂ analyzer is very accurate and stable as shown in Table IV. The percentage deviation from the mean is under 8% for all cases. The same cannot be said about the electrochemical analyzers. The percentage deviation varies between 6 and 100%. NO, present in high concentration underground, has a satisfactory response with less than 25% deviation at all times. On the average, CO has a 30% deviation and NO₂ almost 50% (probably due to the measurements being at the low end of the NO₂ and CO instrument ranges).

TABLE IV
TWA AND CONTINUOUS RESULTS COMPARISON

Date	CO ₂	NO	CO	NO ₂
November 4				
TWA (PPM)	680	2.18	1.0	0.40
Continuous (PPM)	688	2.90	1.5	0.08
Average (PPM)	684	2.54	1.25	0.24
% Deviation	0.5%	14%	20%	66%
November 5				
TWA (PPM)	850	3.68	1.0	0.34
Continuous (PPM)	932	3.30	1.9	0.11
Average (PPM)	891	3.49	1.45	0.22
% Deviation	4.5%	5.5%	31%	50%
November 6				
TWA (PPM)	670	3.01	0	0.21
Continuous (PPM)	647	1.80	1.3	0.08
Average (PPM)	659	2.40	0.65	0.15
% Deviation	1.5%	25%	100%	42%
November 10				
TWA (PPM)	1000	4.17	1.5	0.35
Continuous (PPM)	1093	4.70	3.0	0.21
Average (PPM)	1046	4.44	2.25	0.28
% Deviation	4.5%	6.0%	33%	25%
November 11				
TWA (PPM)	1125	3.44	3.0	0.31
Continuous (PPM)	1172	3.70	4.10	0.12
Average (PPM)	1149	3.57	3.55	0.22
% Deviation	2%	3.6%	15.5%	45%
November 12				
TWA (PPM)	875	2.08	2.0	0.39
Continuous (PPM)	984	3.2	2.2	0.10
Average (PPM)	930	2.64	2.1	0.25
% Deviation	5.8%	21%	4.8%	60%

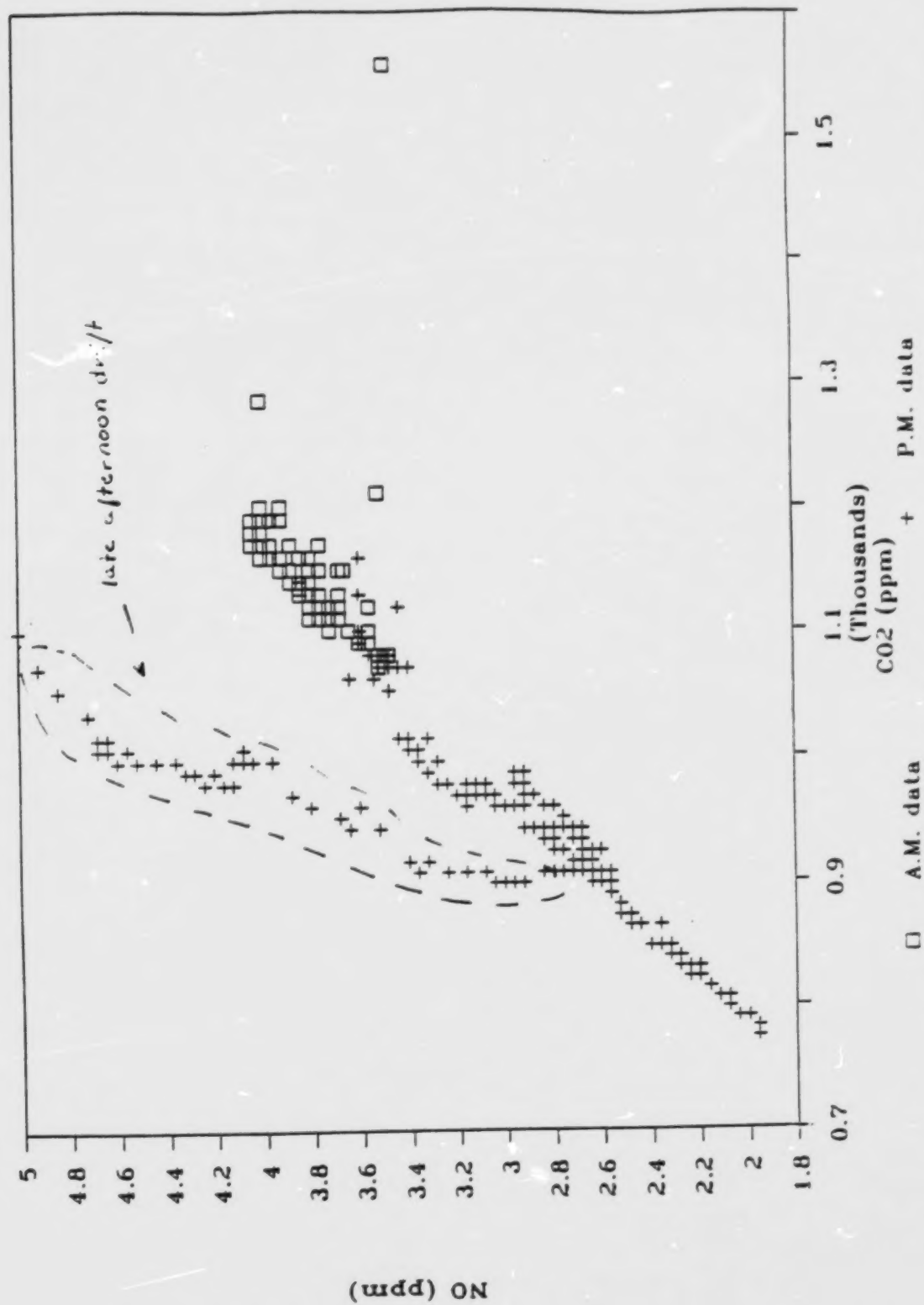


Figure 12 - 725 Meter Level Exhaust Correlation (NO/CO₂)

1000 mL EXHAUST CALIBRATION

November 6th, 1987

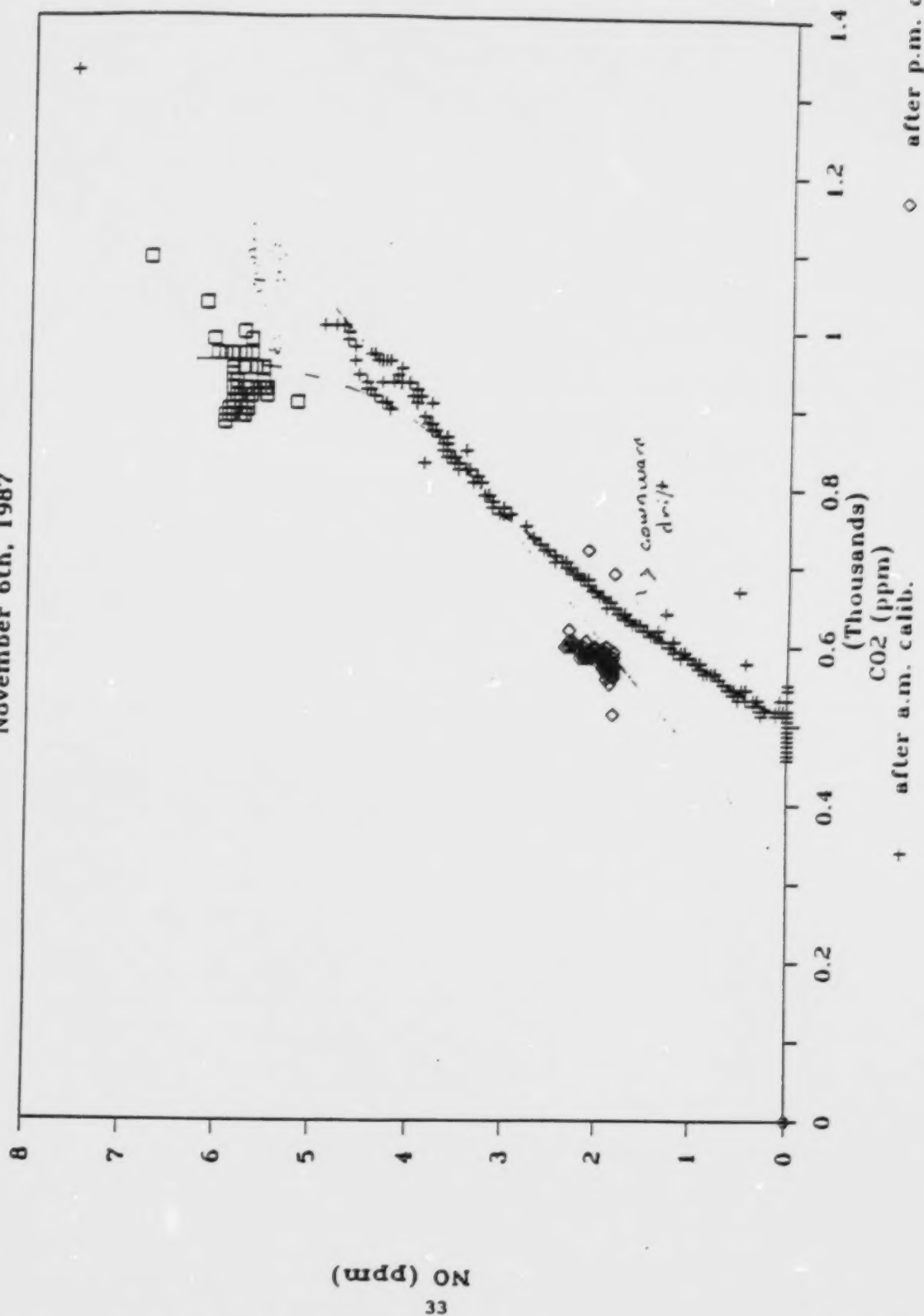


Figure 13 - 1000 Meter Level Exhaust Correlation (NO/CO₂)

3.4.5 Slope of Characteristic Curves

It is important to have a linear relationship between CO_2 and other pollutants if CO_2 can be used as an engineering ventilation control parameter, but it is equally important to be able to predict the slope of the linear relationship. This numerical value of the slope is a function of the type of engine and its condition, the exhaust emission control devices, the duty cycle of the engine, and the operator's habits. All these interrelated variables affect the quality of exhaust emissions so that the curves must be determined from actual underground conditions.

What was not known before the survey, was how much these variables affected the slope. By monitoring different sections of the mines over several days, we collected sufficient data were collected to evaluate whether the slope was significantly affected by changes in diesel equipment and ventilation distribution. In Table III, the CO_2 /contaminant ratios were tabulated in the last column. These ratios vary widely for some of the pollutants, while for others, they are more stable. For example, the CO_2/NO ratio on 725 level lies between 212-231 for an intake station (RPINT) and 223-312 for the exhaust sampling location which is very stable. For the 1000 level, the CO_2/NO ratio varies more widely with 240-421 for the exhaust sampling location and 225-324 for the intake (Intake II).

3.4.6 Factors Affecting an Automated System

The survey took place in early November when the intake air heating system was not functioning. The heating system is a direct propane burner system. The CO_2 produced by the burners is usually around 200-400 ppm when all burners are on. Regular draeger tests are taken on the exhaust side of the burners, and the burners are adjusted when abnormal emissions are detected (300 ppm). It is not known at this time whether the emissions fluctuate considerably over time or if they are fairly steady. This could obviously affect underground CO_2 monitoring and will have to be assessed. If CO_2 is to be used as a control criteria, instruments could be placed in both the intake and exhaust to a section of the mine and the readings subtracted. This method will take into consideration only the pollutants produced on the level, and not re-used air and CO_2 produced by the burner. A fire will also be easier to locate in such a system.

During the survey, very limited data were obtained on rock dust and RCD concentration underground. In a crusher station, the critical parameter to control is the rock dust, as diesel contaminant concentrations should be very low. If the ventilation system is to be entirely automated, it will be necessary to assess rock dust concentration on a continuous basis. Some optical instruments, such as the OSIRIS manufactured in England and Hund of Germany, can be used for such an application and should be evaluated at a future time.

From the TWA samples of RCD and total respirable dust, we were not able to assess the linearity of the CO_2 /RCD relationship. At present, Brunswick and NR are evaluating diesel particulate filters. The results have been very encouraging so far, and some diesel unit fleets could be entirely outfitted in 1988-89. The trap reduces the emission of soot by up to 90%, greatly reducing the health risk of this contaminant. Nonetheless, attempt should be made to evaluate the linearity of the CO_2 /RCD ratio. No instruments are available which give an RCD concentration reading. A Miniram respirable dust monitor could be used to measure continuously total dust and, along with gravimetric sampling, could be used to shed some light on this relationship.

Another factor yet to be considered is oil mist generated by the pneumatic drills. In an area where a drill is operating, the percentage of RCD, which is in reality oil mist, cannot be detected by the analysis method (ashing of the total dust filter), and it can represent as much as 50% of the sample. Oil mist is not toxic like diesel soot and should be subtracted from the RCD measurement. To determine the quantities of oil mist emitted by a jumbo drill at Brunswick, a separate study will be undertaken at the mine.

4. CONTROL PARAMETER: CO_2 SURROGATE

The overall objective of the first field survey is to evaluate the feasibility of using CO_2 as a surrogate for other contaminants and the monitored parameter for feedback to a control ventilation system.

Before explaining how CO_2 would be used for control, present regulations for mine ventilation must be examined. The mine environment regulations in Canada are adopted from the United States regulations. In the United States, the Mine Safety and Health Association (MSHA) is responsible for testing and certifying underground permissible diesel equipment under

regulations contained in the Mining Act, Title 30, Parts 31, 32 and 36 (Schedule 22, 24 and 31). Two of the requirements under this regulation apply to mine air quality and specify: i) the immediate exhaust gas dilution levels; and ii) the quantity of fresh air to be supplied to all sections of the mine. Engines certified by MSHA testing have an approval plate attached to the engine stating the ventilation rate required when equipment powered by the approved engine is operated. The most undesirable and hazardous condition of engine operation is used to prescribe the rate. The maximum quantity of fresh air that reduces the exhaust levels of CO, CO₂ and NO_x in the underground environment to one-half the required tail pipe concentrations is the designated ventilation rate for the given engine.

The approval plate ventilation rate is the quantity of fresh air required for a single unit. If two units are operating in the same split of ventilation air, the ventilation quantity is equal to the sum of the rate for the highest horsepower unit plus 75% of the rate for the lower powered unit. For three or more units working in the same split of air, the rate will be the same as above for the two highest horsepower units and 50% for the others.

In Canada, the ventilation requirements for diesel equipment underground are based on MSHA specifications and are established by the Occupational Health and Safety organization of each province. For New Brunswick, it has been required since 1986 to have all underground diesel equipment certified in accordance with MSHA's criteria and raw exhaust and general working concentrations of CO checked every week (they must be below 1500 ppm and 50 ppm respectively). There are no requirements for NO_x or aldehydes. The Brunswick mine has a special exemption on certain levels because of the history of low CO concentrations, and they are only required to carry CO checks once every three weeks. Brunswick has also set its own underground air quality standard regarding contaminants. Their standard, being much more rigid than the government regulation, requires that CO levels be kept under 20 ppm NO₂ under 3 ppm CO₂ under 5000 ppm and aldehydes under 2 ppm in the ambient atmosphere.

The relationship shown in Figure 1 could be used as a part of a ventilation control strategy. The regulation states that the ventilation rate should be set according to the certification plate of the diesel equipment. It is possible to monitor the CO₂ generated in a section and plot the CO₂ concentration on the curve of Figure 1 to find out the CFM/BHP delivered to this section. The ventilation can then be automatically adjusted to bring the CFM/BHP to the level stipulated by the certification plates of all the diesel in this section.

The certification method is a good tool for regulation, but it has a serious drawback. Bench tests are run in a lab to certify the engine. After several hundred hours of operation underground, the composition of the exhaust for the engine tested can vary substantially. Proper control of ventilation should therefore monitor the quality of the exhaust and not only the CFM/BHP delivered.

This is why the linearity of the relationship between the CO_2 and the other contaminants is very important. It makes it possible to control ventilation not based on CFM/BHP alone, but also direct air quality. The concern for the health of the workers is better addressed by this technique. One difficulty of the approach is the necessity of knowing the distribution and composition of the diesel fleet in a section in order to adjust the CO_2 /contaminants ratios appropriately.

To adjust the ratios, good underground monitoring must be undertaken. The survey should identify the two most critical contaminants and verify the ratios for only these two pollutants, thus simplifying the overall study.

5. CONCLUSIONS OF FIRST FIELD SURVEY

The following are conclusions based on the field investigation at Brunswick.

1. The validity of the linear CO_2/NO relationship was demonstrated for multiple diesel equipment operating in the same split of air.
2. The NO_2 and SO_2 being very unstable and present at very low concentrations were impossible to monitor properly with present instrumentation, however, fair relationships were nonetheless found. Both are present underground at less critical concentrations than NO.
3. CO is greatly reduced underground at BMS-M by the use of catalytic converters. The correlation for linearity with CO_2 was low, probably due to the inaccurate analyzer in combination with the effect of catalytic converters.
4. Respirable combustible dust (RCD) was present at the highest percentage of its currently recommended limit of 2 mg/m^3 underground. The linear relationship could not be verified as there exists no continuous RCD analyzers. The implementation of ceramic filters at BMS-M will reduce the generation of soot.
5. The ratios of CO_2 vs other contaminants varied significantly when compared for different days or sections of the mine. Factors such as diesel fleet distribution and composition appear to affect the ratios to the extent where knowledge of these factors will be required to adjust the ratios daily for automated control.
6. Other factors influencing automation such as CO_2 emission by the burners and oil mist generation were not studied in this survey, but require consideration in the next survey.

Overall, the survey was a success. The linearity of CO_2/NO , CO_2/NO_2 and CO_2/SO_2 relationships were demonstrated. Carbon dioxide has therefore good potential for use as a major control parameter in an automated system.

6. RECOMMENDATIONS OF THE FIRST SURVEY

The following are recommendations for additional research to further develop the CO₂ surrogate approach and to provide a better understanding of various factors involved with automation.

- For the first survey, the accuracy of the instrumentation used was sufficient to establish trends. Nonetheless, a second survey will have to be undertaken. The instrumentation, which could be used in a mine control system, must be identified and tested in the second survey in order to evaluate their reliability underground.

A thorough investigation of available sensors was undertaken at the end of 1987. Instruments have been identified for gases. A continuous RCD monitor could not be identified. An option is to use the Miniram (or RAS-I) to measure total dust and extrapolate RCD concentrations.

- Separate surveys will also be required to assess generation of CO₂ by the burners, problems with ventilation automation in the crusher station, and contribution of oil mist to the RCD measured by gravimetric method.
- Finally, sensitivity of characteristic curves' slope must be addressed. The necessity to monitor equipment movement in and out of a section underground to adjust the slopes should be evaluated. This could be a considerable drawback in an automated system.

7. SECOND FIELD SURVEY AT BMS-M

7.1 Objectives

The second field survey had three distinct objectives:

1. Test the reliability of instrumentation to be used in a control system.
2. Assess the generation of CO₂ by the propane burners and the generation of oil mist by hydraulic equipment.

3. Investigate the feasibility of monitoring equipment movement in and out of a section to adjust the slopes of CO₂ / contaminants.

7.2 Monitoring Strategy

The underground survey was undertaken over the first two weeks of February 1989. One engineer and one technician from NTC as well as two consultants from Decibel Consultants Inc. were involved in the work.

All the instrumentation utilized was purchased by NTC. The instruments are manufactured for underground continuous monitoring and were selected based on a thorough investigation conducted by NTC. NO₂ sensors were not purchased because the investigation showed that no instruments with reasonable accuracy are manufactured for concentration ranges around 0.1 - 1.0 ppm (the range found at BMS-M). Table V gives a list of equipment used in the study.

The instruments were set up to provide two full monitoring stations plus spares. The Sieger CO₂ sensors were set up to monitor directly on the LHD and trucks with Squirrel data logger. The Squirrel data loggers were not the same as the one used in the first survey. They were of the series 2000 with 12 bits of accuracy instead of 8.

Figure 14 illustrates a schematic of the 1000 mL mining area. This is the area where all the monitoring was undertaken. In the first four days of the survey, the stations were set up on the 1000 mL sill (Figure 15). In the second week the stations were installed on No. 2 sub (Figure 16) and the V-4 exhaust.

The 1000 mL area is presently composed of the sill level where the drawpoints are set up and two sublevels. No. 1 sublevel is very active and No. 2 sub is recent and there is only one scoop operating on this level each shift.

TABLE V
INSTRUMENTS LIST

Carbon Dioxide Monitor

2 - Sieger Model 5050 (0-4000 ppm)

Specifications : No calibration required (contains a linearization table in memory of u controller and has built-in zero reference capabilities).

-	Response time :	5 sec
-	Linearity :	better than 3% FSD
-	Operating humidity :	0-99% R/H (noncondensating)
-	Stability (zero, with time, pressure, temperature, humidity) :	3% RSD / year
-	Stability span :	5% FSD / year
-	Power input :	24 Vdc
-	Output :	4-20 Ma / RS 485

2 - Gastech Model 3600 (0-5000 ppm)

Specifications :	-	Output :	nonlinear
	-	Output :	4-20 Ma
	-	NDIR sensing	
	-	Power input :	24 Vdc
	-	Two adjustable alarm settings	
	-	Response time :	20 sec

Carbon Monoxide

3 - Dowty PF Series Transducer (0-40 ppm)

Specifications :	-	Electrochemical cell	
	-	Linear output :	4-20 Ma
	-	Power consumption :	10 mA
	-	Humidity :	95% noncondensing
	-	Overall accuracy :	2%
	-	Maximum drift (zero & span) :	2% / month
	-	Repeatability :	0.5%
	-	Response time :	20 seconds (90%)
	-	Cell life :	1 - 2 years
	-	Supply :	24 volts

Nitric Oxide

3 - Dowty PF Series Transducers (0-25 ppm)

Specifications : - Same as for CO sensors

Sulphur Dioxide

2 - NTC built sensors

Specifications : The electrochemical cell is the same as for the Dowty PF Series and the specifications are similar

1000 ml VENT. SCHEMATIC

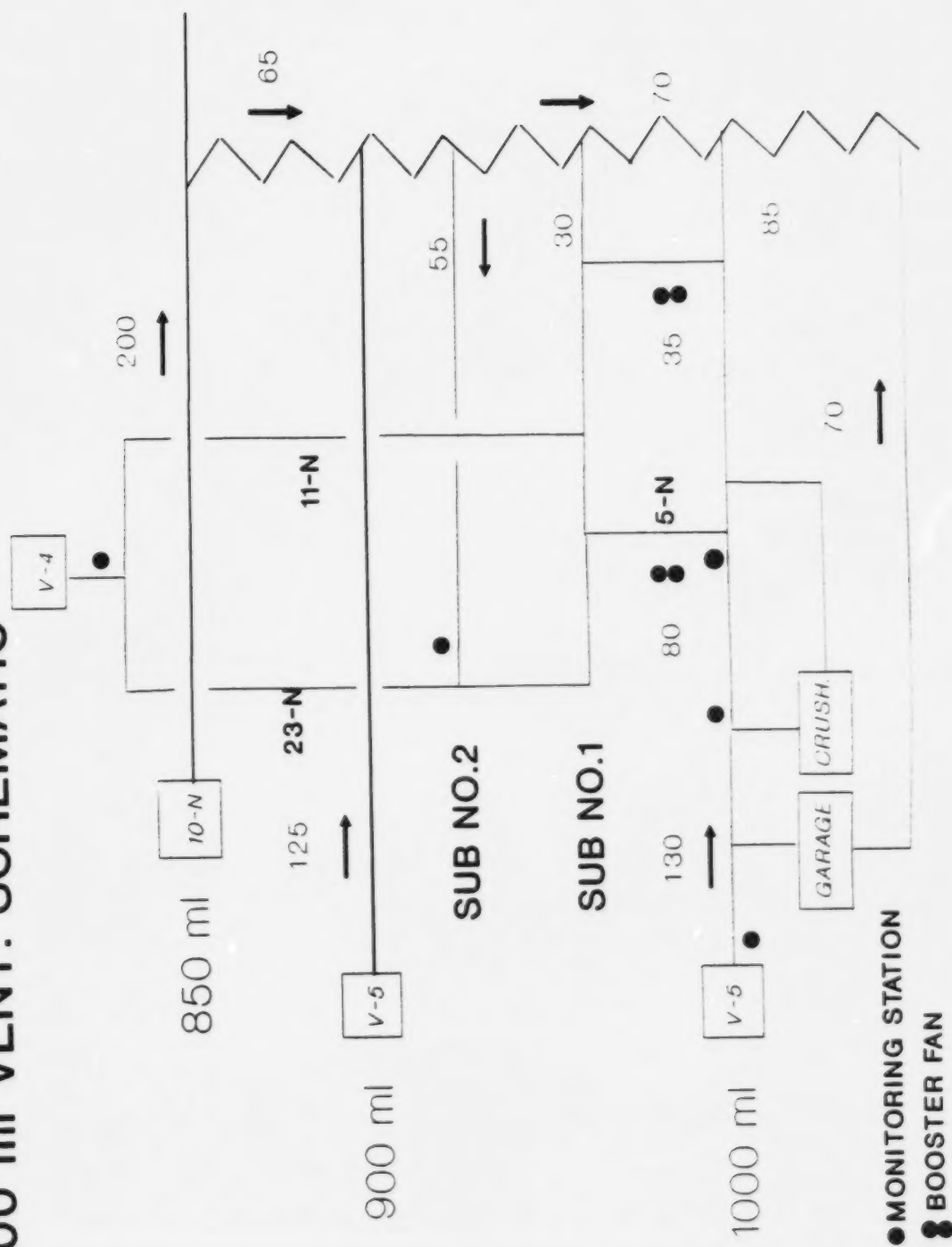


FIGURE 14 1000 mL SCHEMATIC

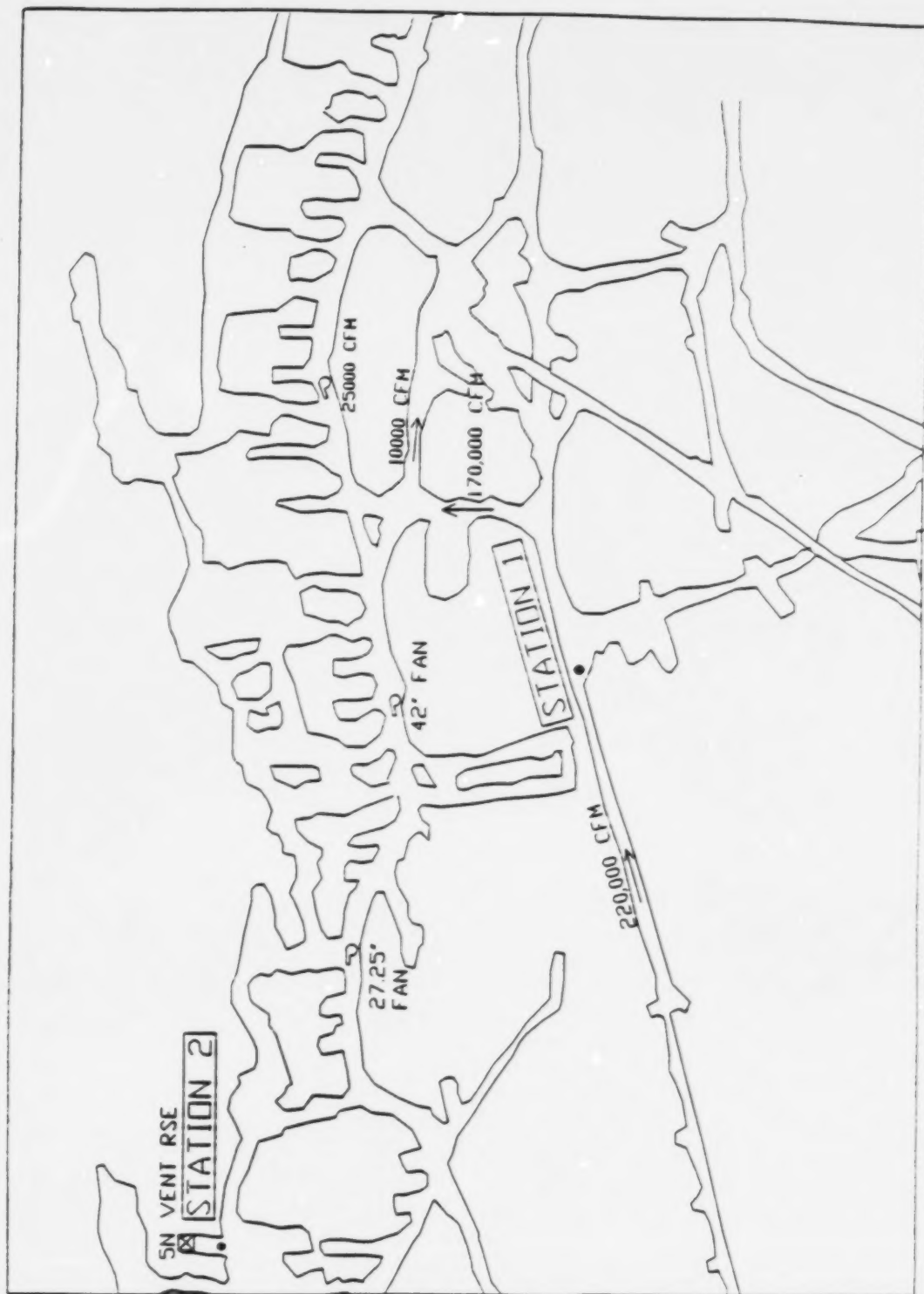


FIG. 1'5 1000 mL SILL STATIONS SET-UP

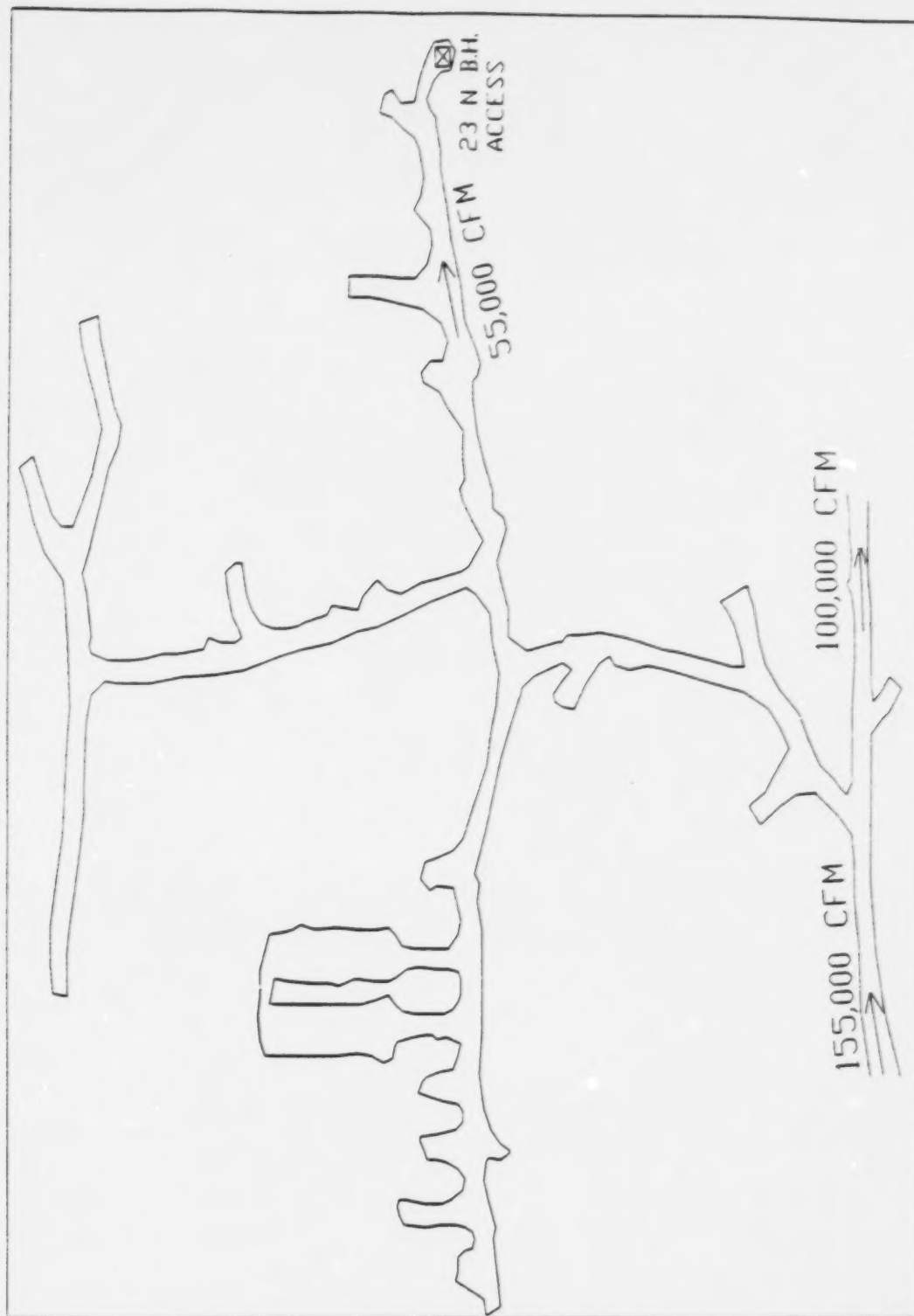


FIG. 16 No. 2 SUB SET-UP
(STATION INSTALLED NEAR THE 23 N B.H.)

The ventilation is provided entirely by the V-5 intake. On the sill, the north zone is largely mined and only the south zone remains active. The air is supplied by the V-5 intake on the sill and is exhausted to the No. 1 sub via a booster fan. The north zone is supplied by air from the ramp and this air is also exhausted to the No. 1 sub via a second booster fan. No. 2 is entirely supplied by air coming from the ramp which is supplied by the V-5 on 850 and 900 mL. The air is exhausted to the 11-N raise. No. 2 is also partly supplied from the ramp in addition to the north and south sill zone. It exhausts its air via the 11-N and 23-N. The 11-N and 23-N join the V-4 main exhaust. A total of 400,000 cfm is supplied to the 1000 mL beat.

7.3 Results

7.3.1 Propane Burners

The temperature during our survey varied from as high as -3°C to as low as -25°C . This is significant since the propane burners are turned on by rows depending on outside temperature. The temperature is monitored by a thermistor, and a programmable logic controller controls the amount of burners required to heat up the intake air to $+1^{\circ}\text{C}$.

The products of the propane combustion are CO and CO_2 . In a very efficient flame, the maximum CO_2 produced should be around 300 ppm and the CO no more than 3 ppm. BMS-M tries to maintain the efficiency at these levels through monthly checks.

During the period of our survey, we encountered some abnormal CO and CO_2 levels. The CO generated by the burners exceeded 8 ppm and the CO_2 , 1100 ppm. Figure 17 shows a typical CO and CO_2 readout from the V-5 intake. On this graph we can clearly see the turning off of two rows (or more) of burners.

In the first part of the graph the CO rises while the CO_2 is reduced. This is not associated with changes in the number of burner rows in operation, it is associated with the efficiency of combustion.

There is an optimal speed at which the air must flow across the burners for them to be efficient. When this speed is not maintained, the CO will increase and the CO_2 decrease. In Figure 17 the CO increases in the first hour of the shift (and the CO_2 decreases) and this represents a change in air volume handled by the main fans. At the beginning of a shift the

CO and NO Emission, V-5 Intake

20 February (Day)

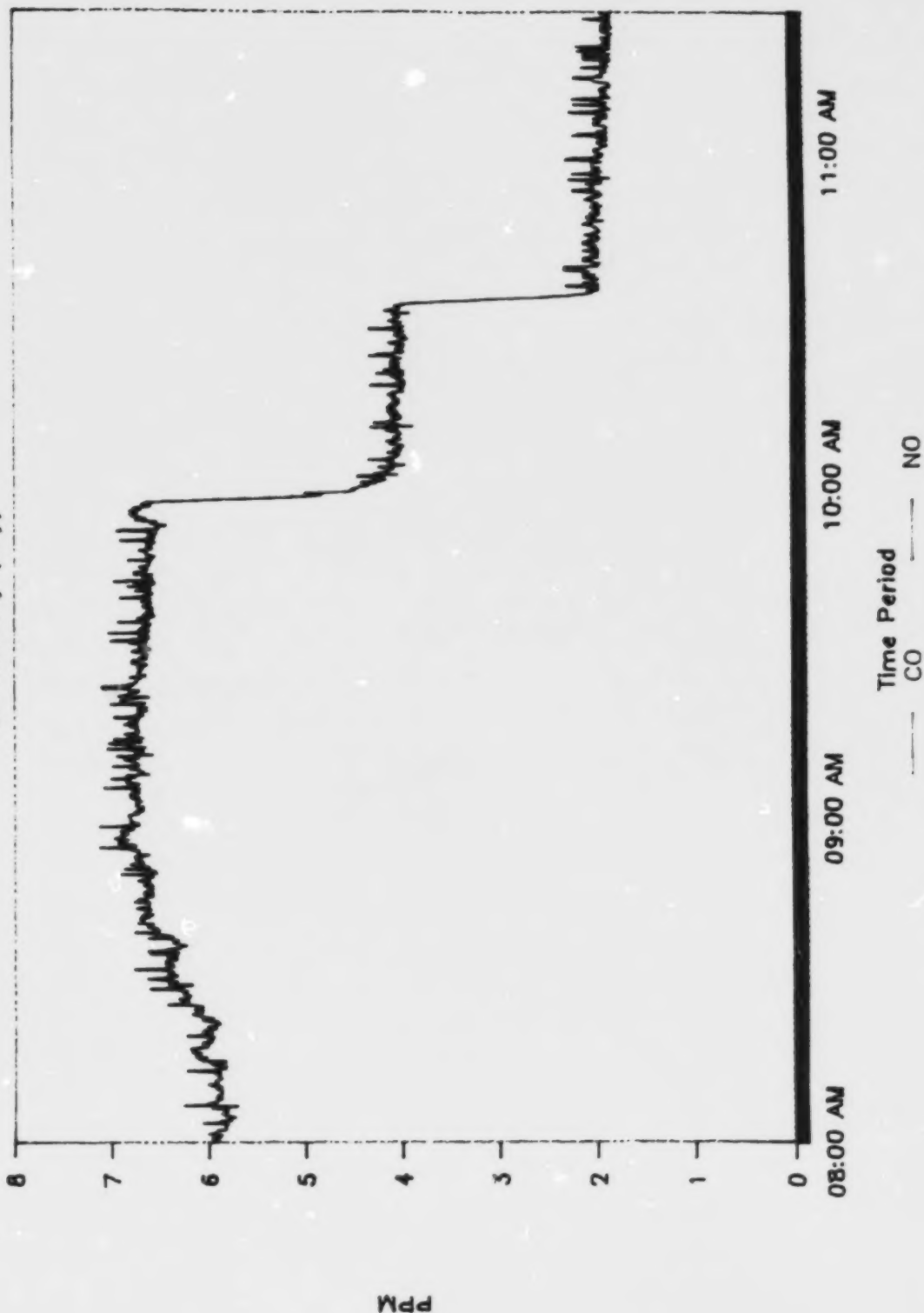


FIGURE 17

resistance of the mine probably increases as the activity increases, creating a decrease in the main fan volume. Figure 18 is another example of this relationship. It can be seen that the flow can have a large influence on the efficiency.

In summary, to predict the amount of CO and CO₂ produced by the burners, it is not only necessary to know the number of rows burning and their efficiency curves but also the air volume handled by the fans.

In the next chapters, the results presented have been corrected for CO and CO₂ generated by the burners.

7.3.2 1000 mL Sill Results

On-board Monitoring

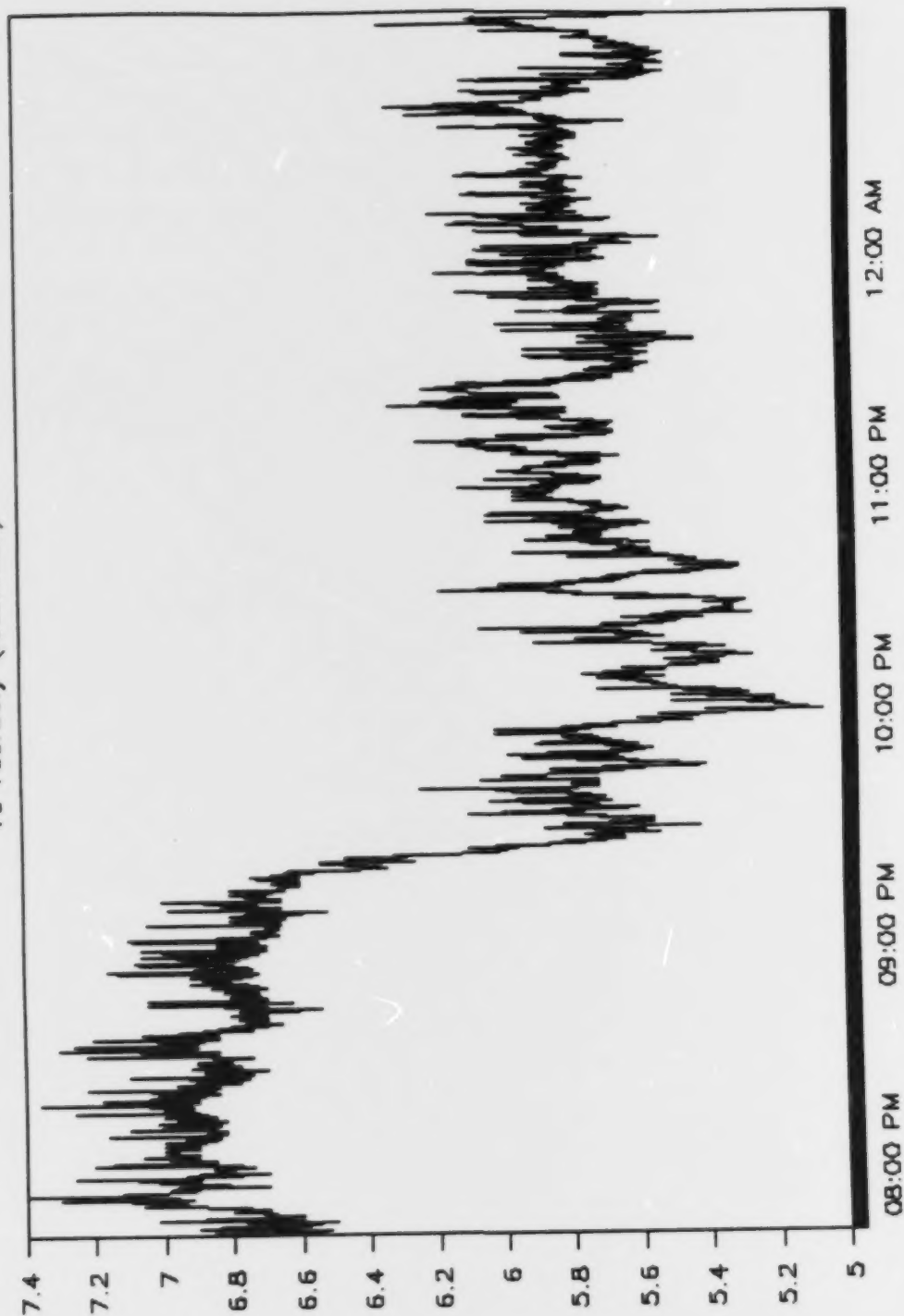
During the first two days on the Sill, while the stations were prepared for the monitoring, the CO₂ Sieger monitors were installed on a truck and a scoop. The CO₂ monitors failed to work after two days of operation and could not be repaired on site. It was later explained to us by Sieger engineers that the microprocessor program in the units had been erased through a power surge. The units were connected to the 12 V battery on the scoop and truck. In operation, the voltage can jump slightly and the Sieger instruments are apparently too sensitive for such use.

Nonetheless, some data were acquired. Figures 19A and B are graphs of the CO₂ generated on a scoop on the sill. In Figure 19A, the background level of CO₂ is 800 ppm (propane burner generated) and the three cycles of mucking in a drawpoint and tramming to an ore pass can be seen. The operator's breath averages 600 ppm of CO₂ (corrected for background). After mucking in the drawpoint, the operator went to clean-up in a dead-end stope. The CO₂ went up to 2800 ppm (2000 ppm if corrected). The CO₂ then returned to background once the machine was stopped near the V-5 intake.

In Figure 19B, the scoop is used to load the truck from a drawpoint. The lunch period is clearly defined at 7:00 p.m. the background of CO₂ steadily climbs to 1050 ppm from 950 ppm at the beginning of the shift. the average CO₂ measured during mucking is 1280 ppm (280 ppm if corrected for background).

CO Emission, 1000 V-5 Intake

19 February (Afternoon)

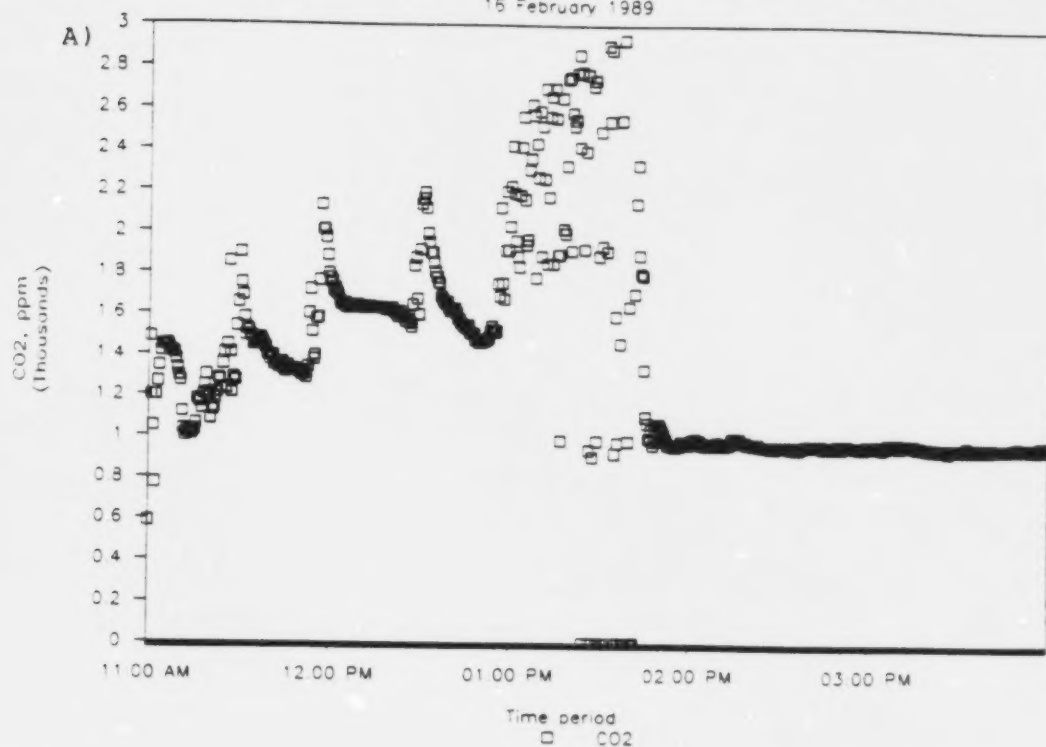


Time period — CO

FIGURE 18

Carbon Dioxide Emission, Scoop VL184

16 February 1989



Carbon Dioxide Emission, Scoop VL134

16 February 1989

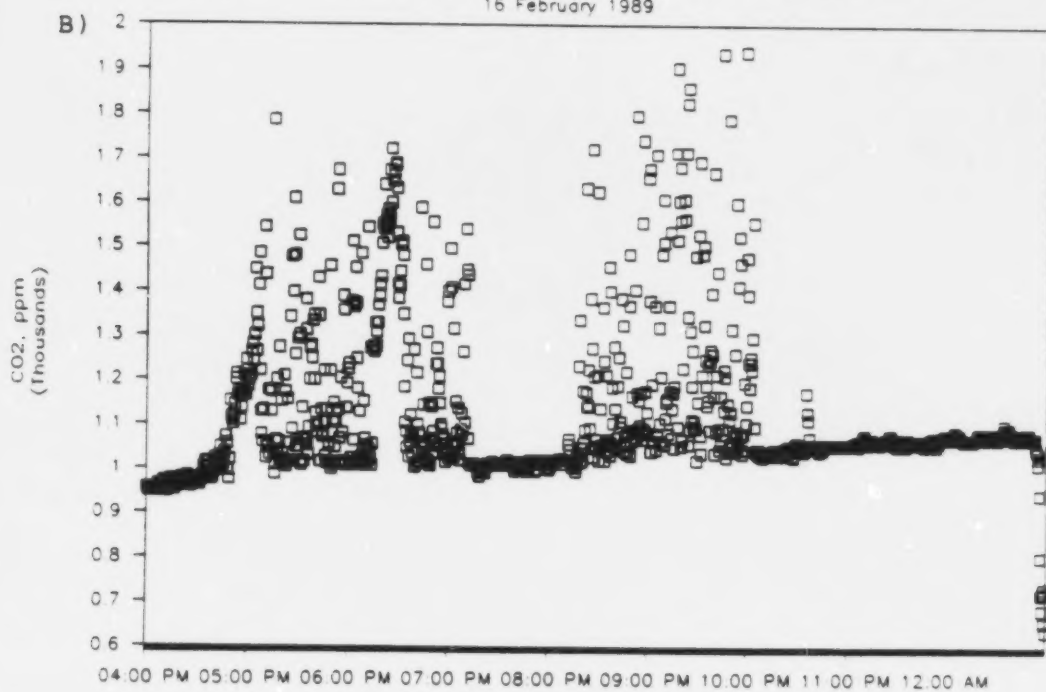


FIGURE 19

Figures 20A and B present the results for the truck. The results are similar. The background level is 800 ppm and the average CO₂ produced during tramming is 1185 ppm in 20A and 1270 ppm in 20B.

South Sill Monitoring

To monitor the south sill diesel contaminants generation, a monitoring station was installed near the 5-N borehole where the air is exhausted to the No. 1 sub. A second station was placed in the main tramming access to compare the contaminant levels near the diesel equipment with the diluted contaminants at the exhaust side.

Figure 21 is an example of diesel contaminants trace. The SO₂ results do not appear on the graph since the levels are too low to be detected by the sensors. The background level of CO₂ is around 650 ppm and 3.5 ppm for CO.

The graph shows almost a perfect relationship between the NO and CO₂. (Unfortunately, the x-axis of the CO₂ graph is slightly longer than the x-axis of the CO/NO, so the peaks of the NO and CO₂ do not exactly match).

The CO is very high because of the propane burners, but it can be seen that the diesel effect is very small compared to the NO.

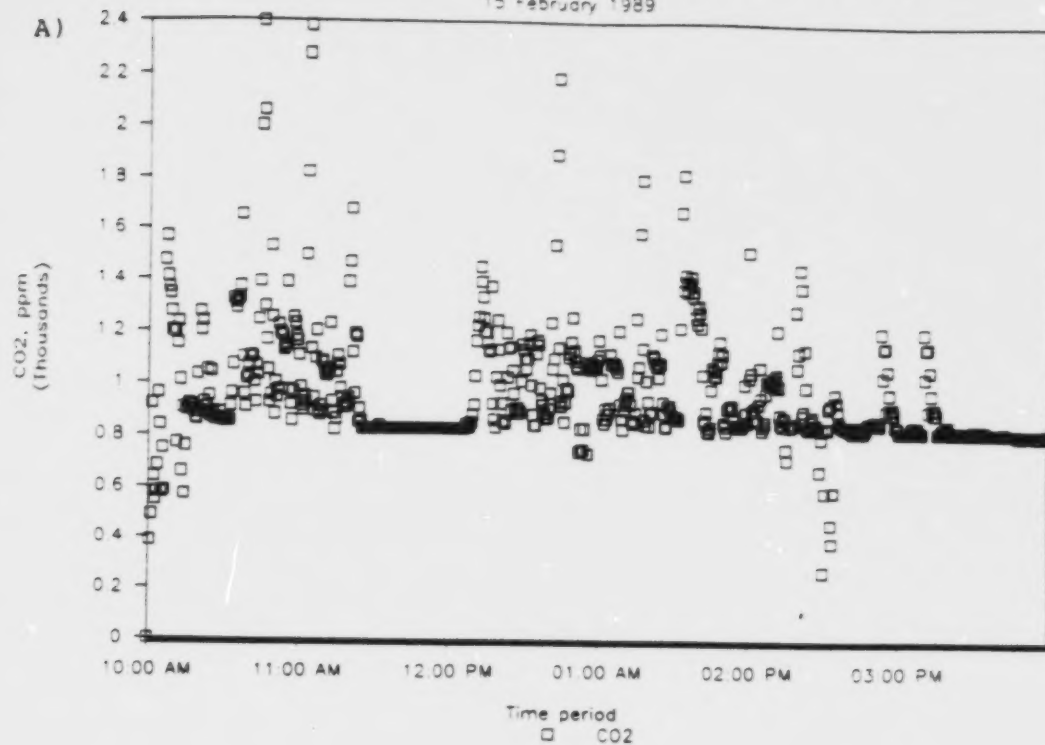
Figure 22 represents another usual example of the traces monitored. The NO/CO₂ trace is a perfect match. The CO follows the other traces trend but is not generated in large quantities.

Figure 23 is a third example of the good relationship between the CO₂ and NO. A burner row is turned on at 3:00 a.m. and the CO₂ level in the V-5 intake consistently increases thereafter. This effect can be seen on the CO also. The small peak at lunch break (5:30 a.m.) was caused by a tractor parked near the instruments.

Figure 24 represents monitoring of a development blast (the CO₂ trace is unavailable). The background level of CO is 5 ppm and the CO produced by the blast is 12 ppm. The NO produced by the blast is only 3 ppm. The level goes back to zero before production resumes. The CO level takes longer to clear and it is not cleared before production resumes. The two traces are very similar.

Carbon Dioxide Emission, Truck VH151

15 February 1989



Carbon Dioxide Emission, Truck VH151

15 February 1989

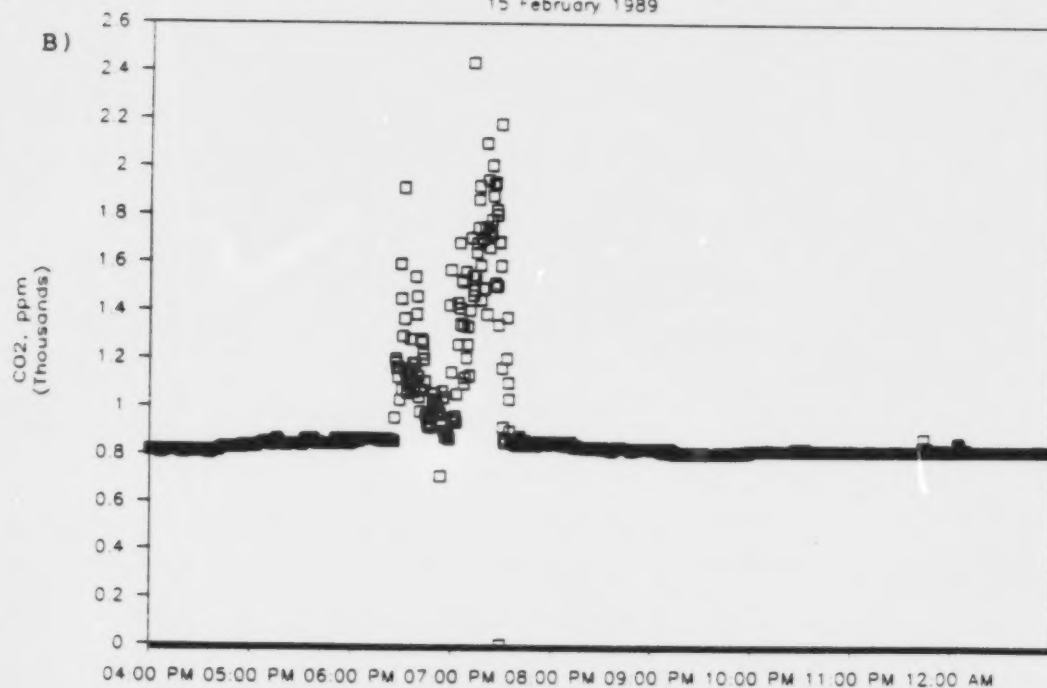


FIGURE 20

1000 South Exhaust

17 February (Day)

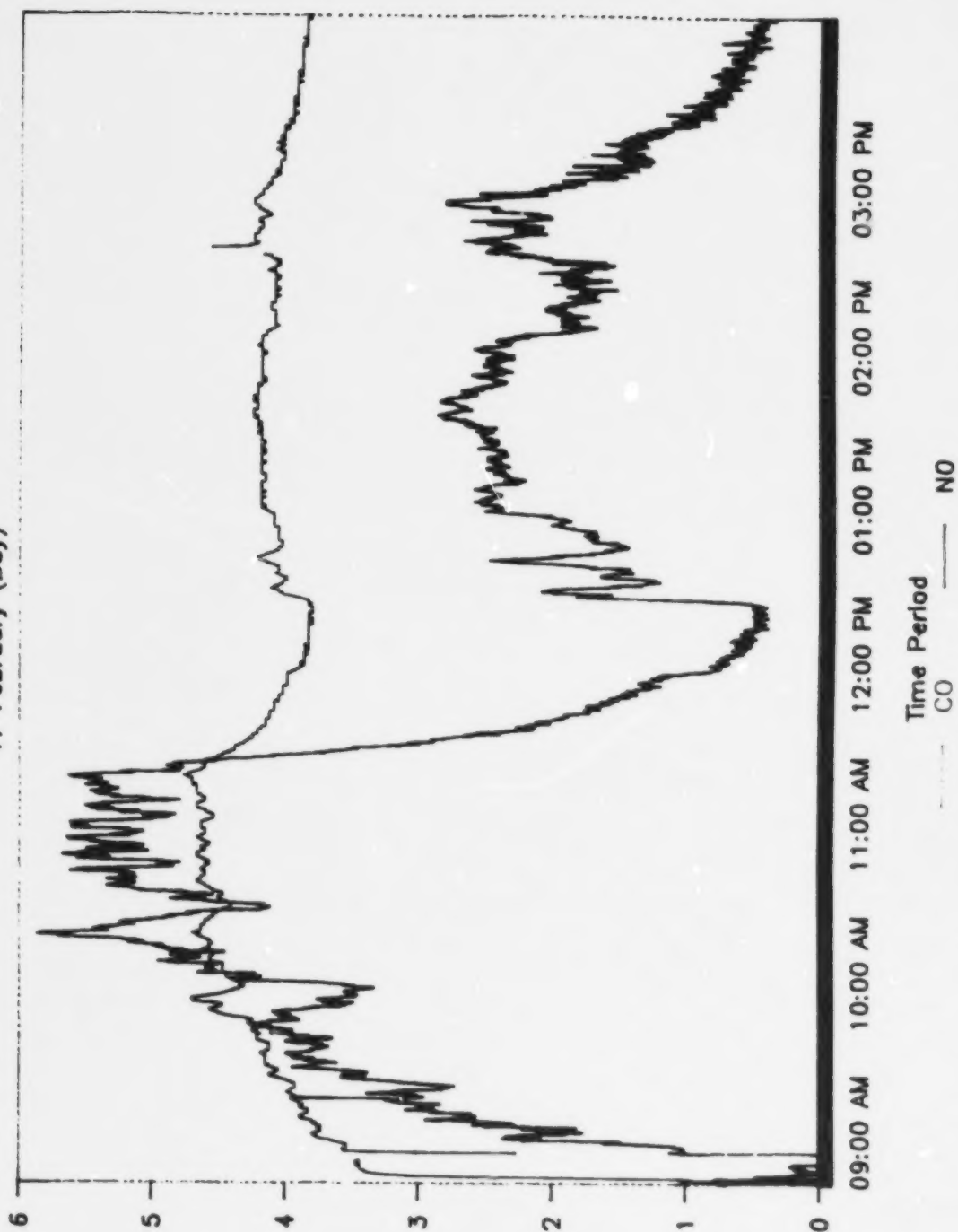


FIGURE 21

CO and NO Emission, 1000 South Exhaust

17 February (Afternoon)

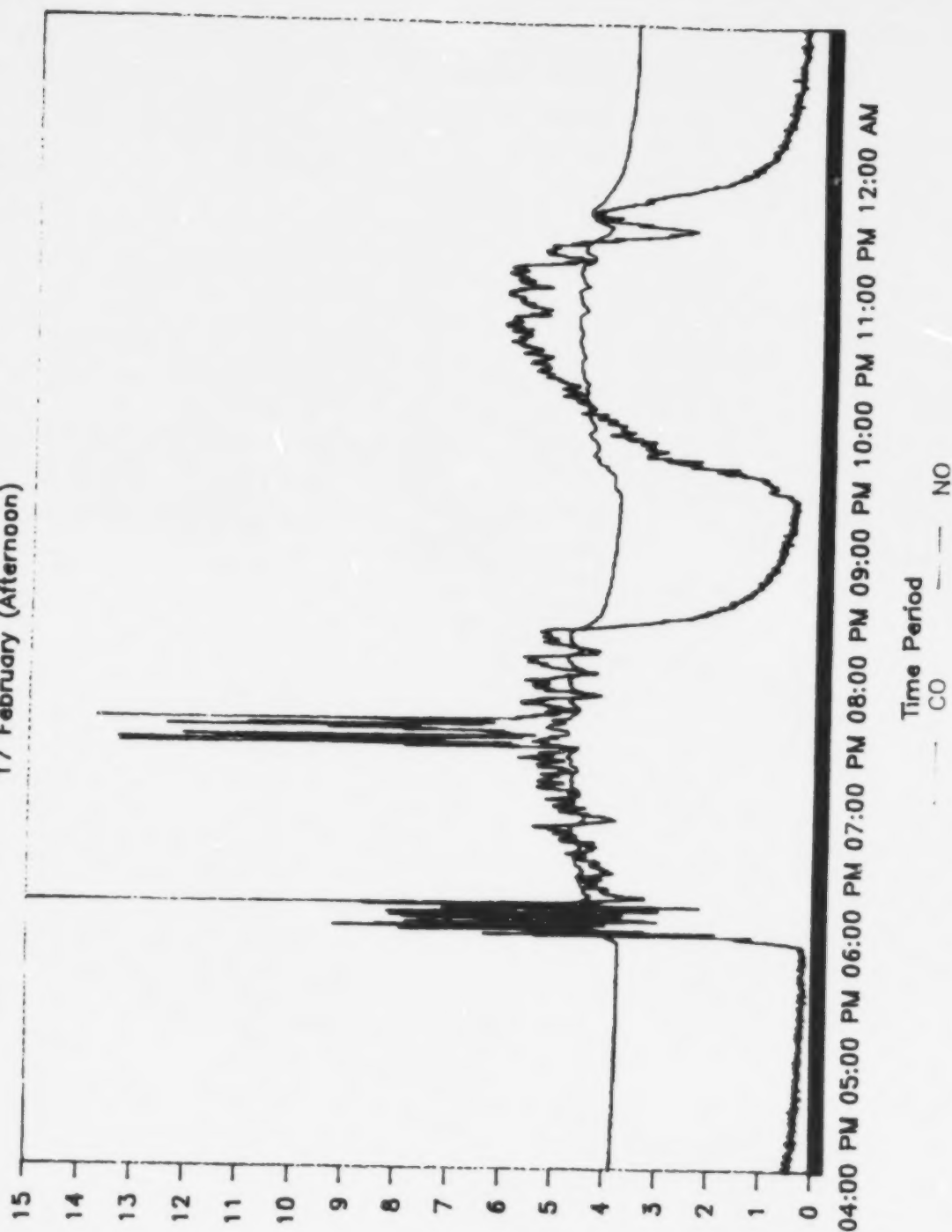
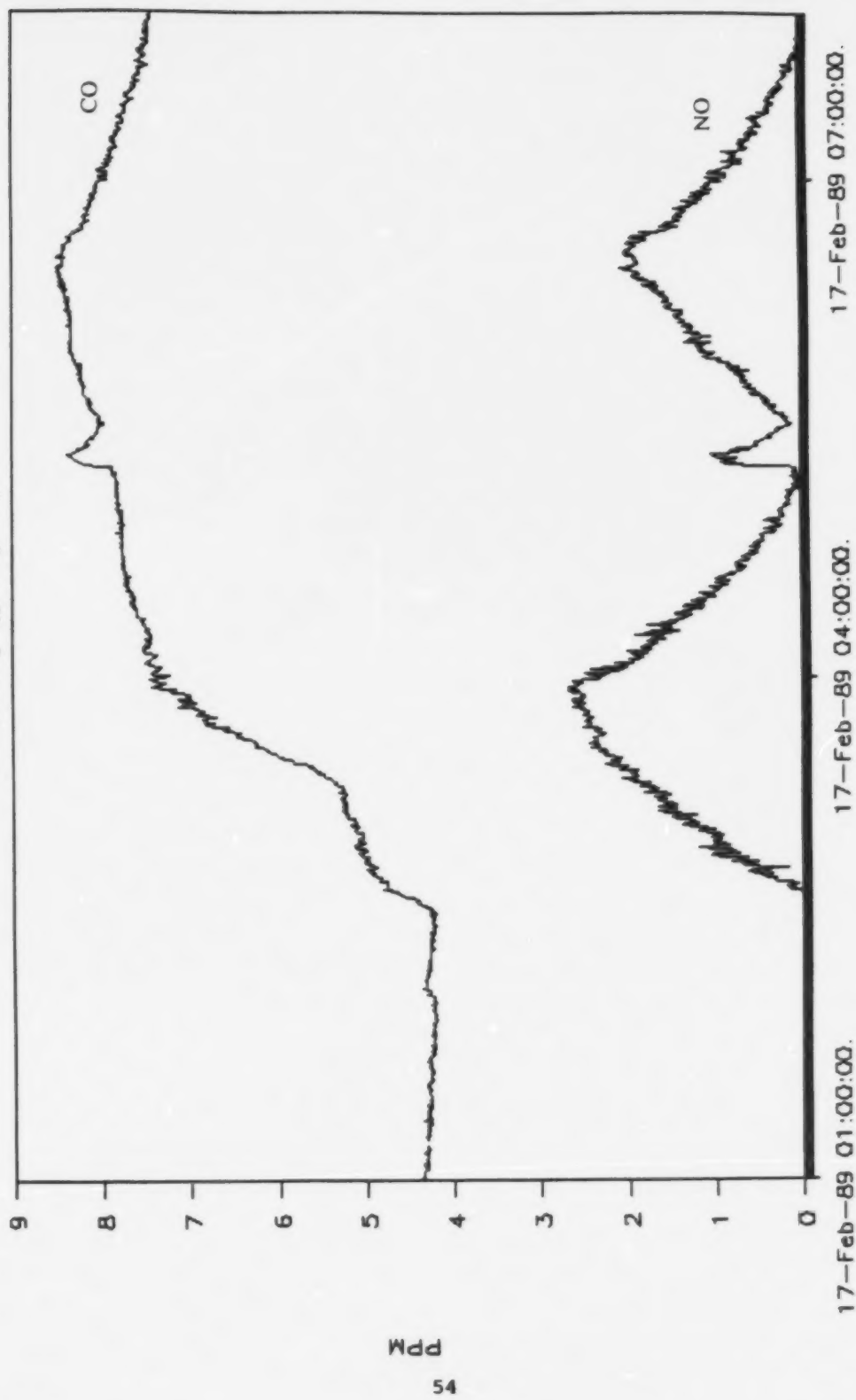


FIGURE 22

CO and NO Emission, Sill Exhaust

17 February (graveyard)



Time period

FIGURE 23

NO and CO Emission, Sill Exhaust

16 February (Afternoon)

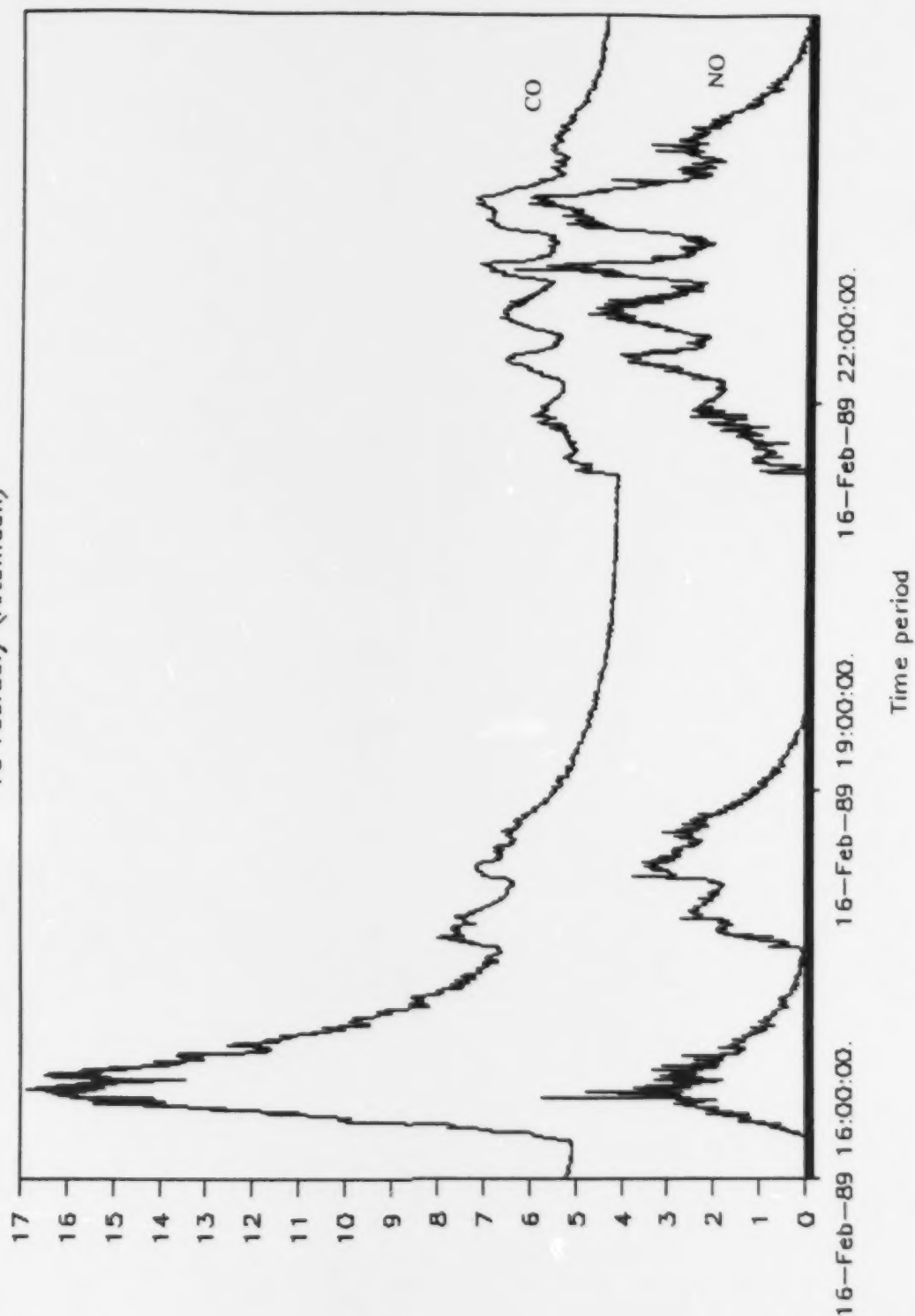


FIGURE 24
(Traces Include Development Blast)

Figure 25 represents a product blast which includes a CO₂ trace. There was no production on that shift since the blast was delayed to 2:00 a.m. The background level of CO was 3.8 ppm and 1080 ppm for the CO₂. The blast generated again twice as much CO as NO. Surprisingly, the CO₂ was not affected significantly by the blast and only 150 ppm was generated. The propane burners were turned off slowly and 30 minutes before the end of the shift they were all off.

Figure 26 shows a trace of CO₂/NO/CO in the main tramming road. One truck was tramming between a south zone drawpoint (where a scoop was loading). The background level of CO and CO₂ varied substantially during the shift. The NO almost reached the sensor limit of 25 ppm every time a truck went by. The CO was not affected significantly by the truck while the CO₂ was affected marginally.

Figure 27 shows a trace when two scoops were operating between south zone drawpoints and an ore pass. The CO, CO₂ and the NO are very similar. The background level of CO₂ rose by 300 ppm at 6:00 p.m. and this is why the CO₂ and NO do not match perfectly. The CO was again generated in small quantities (in comparison to the NO).

7.3.3 1000 mL No. 2 Sub Results

There was not much activity on the 2 Sub when we monitored the exhaust side. It was planned to have one scoop mucking at all times but equipment breakdown forced a change in schedule. Most of the diesel generated was due to the activity at the ramp. The ore pass in No. 1 Sub was filled up frequently during our survey and the trucks had to go up the ramp to 850 mL in order to unload. Usually two trucks would be in operation in the ramp.

Figure 28 shows a typical sensor output from such a shift. the NO/CO₂ curves are a perfect match. In Figure 29 the trucks did not operate in the afternoon and the monitoring was only initiated at 11:00 a.m.

CO and NO Emission, 1000 South Exhaust

18 February (Graveyard)

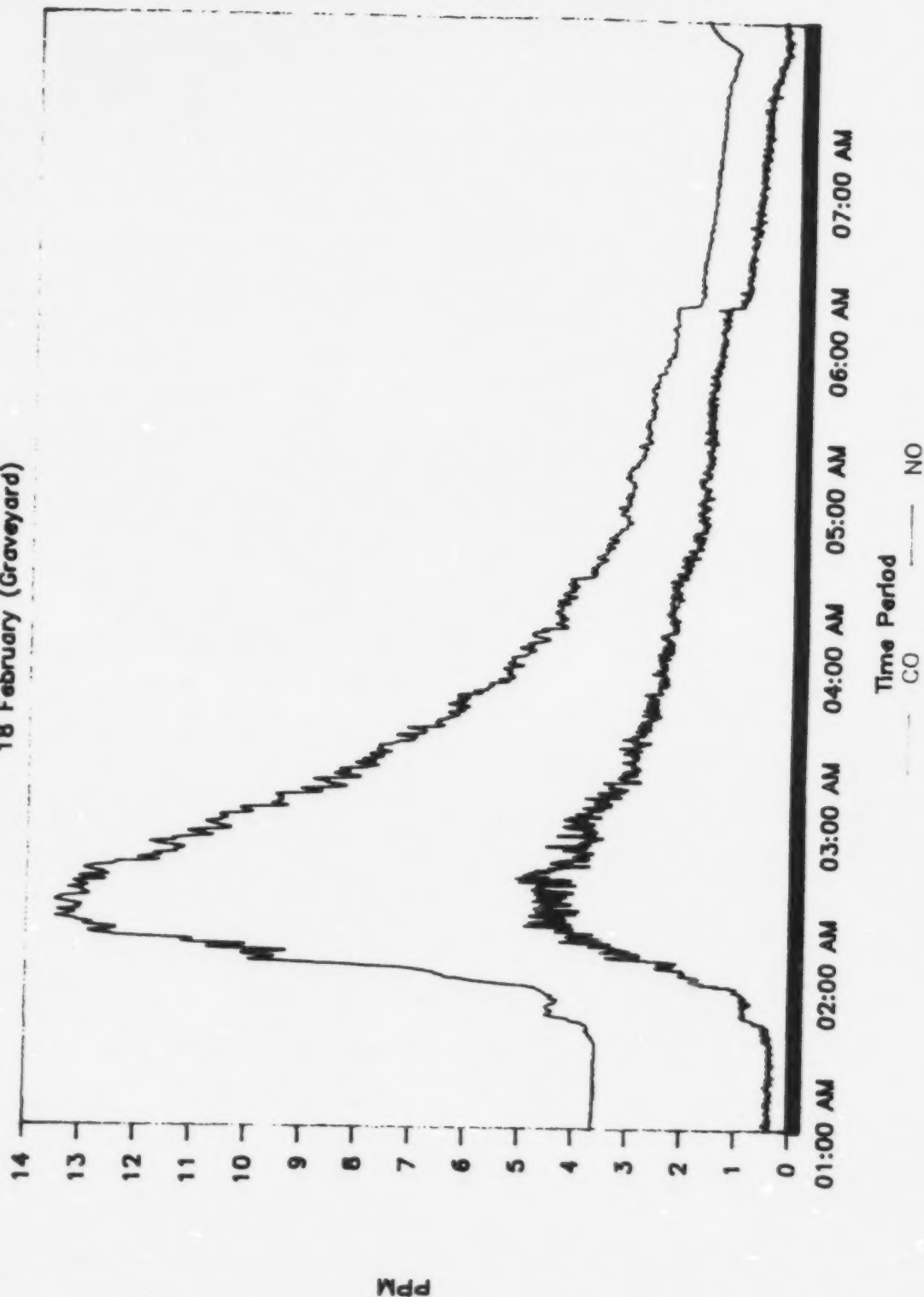


FIGURE 25
(Traces Include Production Blast)

CO and NO Emission, 1000 South Access

18 February (Graveyard)

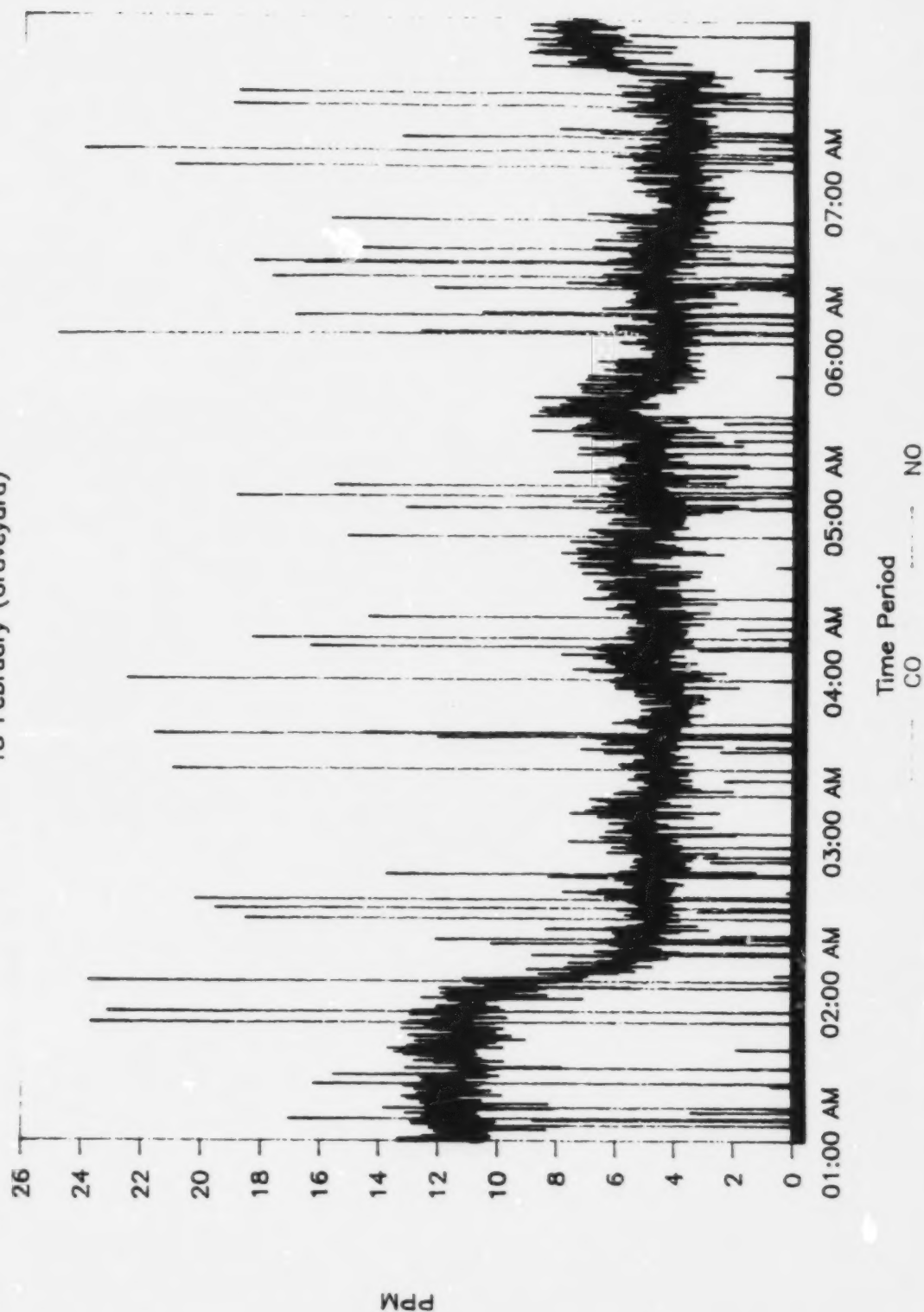


FIGURE 26

NO and CO Emission, 1000 South Access

18 February (Afternoon)

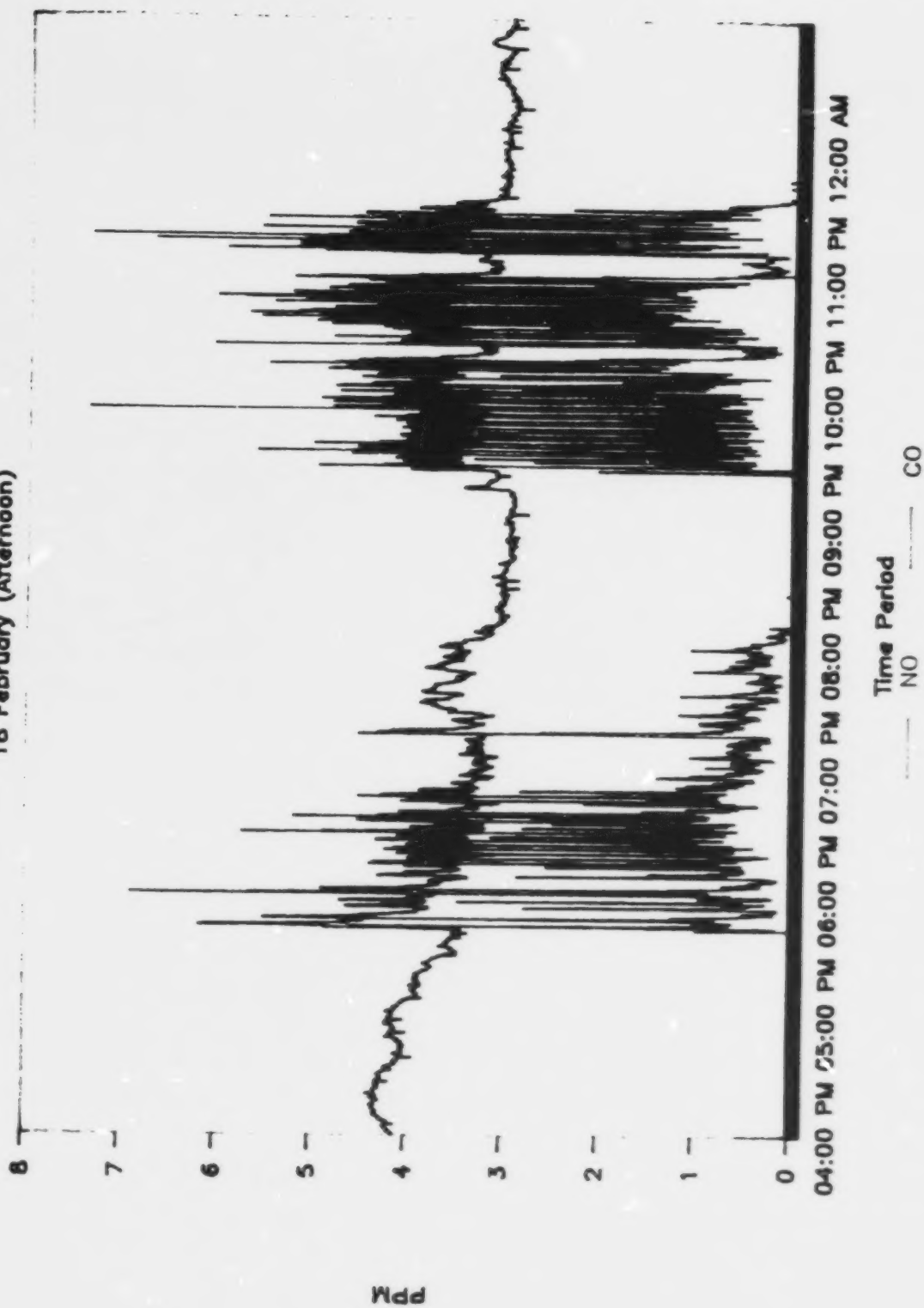


FIGURE 27

CO and NO Emission, 1000 2sub Exhaust

22 February (Afternoon)



Time Period

FIGURE 28

CO and NO Emission, 1000 2sub Exhaust

22 February (day)

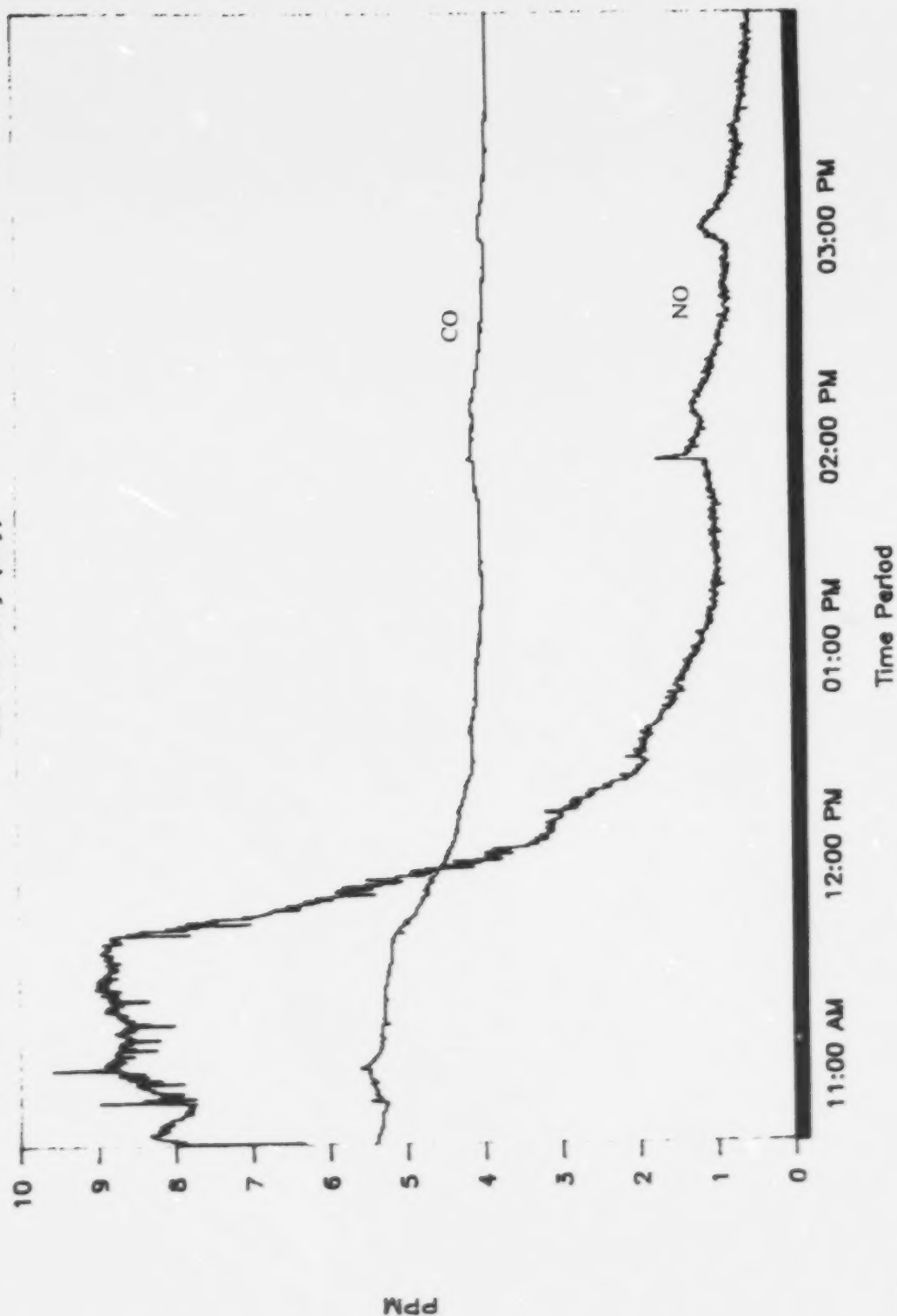


FIGURE 29

7.3.4 1000 mL V-4 Exhaust Results

The CO₂/NO correlation was not as good for the total exhaust, but it was still quite acceptable. The CO/NO correlation on the other hand was improved.

Figure 30 presents the results from the first shift of monitoring. The CO/NO correlation is near perfect. The CO₂ trace also is similar to the other traces but does not match. In the middle of the shift at 8:40 p.m., there was a slash blast on the sill and it was picked up clearly by the NO and CO monitors. The CO₂ barely reacted.

Figure 31 is a trace of a development blast on the No. 2 Sub. The maximum concentration is much higher than for a development blast on the sill as both sensors went out of range. This is because more than 50% of the air exhausting the level was circulated through the development heading. On the sill, only 10-20% is circulated through the headings.

Figure 32 presents results from the only SO₂ secondary explosion monitored during the survey. The explosion occurred on the sill from two adjacent development headings simultaneously blasted. the level of ventilation was 45,000, so the actual peak SO₂ level reached in the headings could have been over 200 ppm.

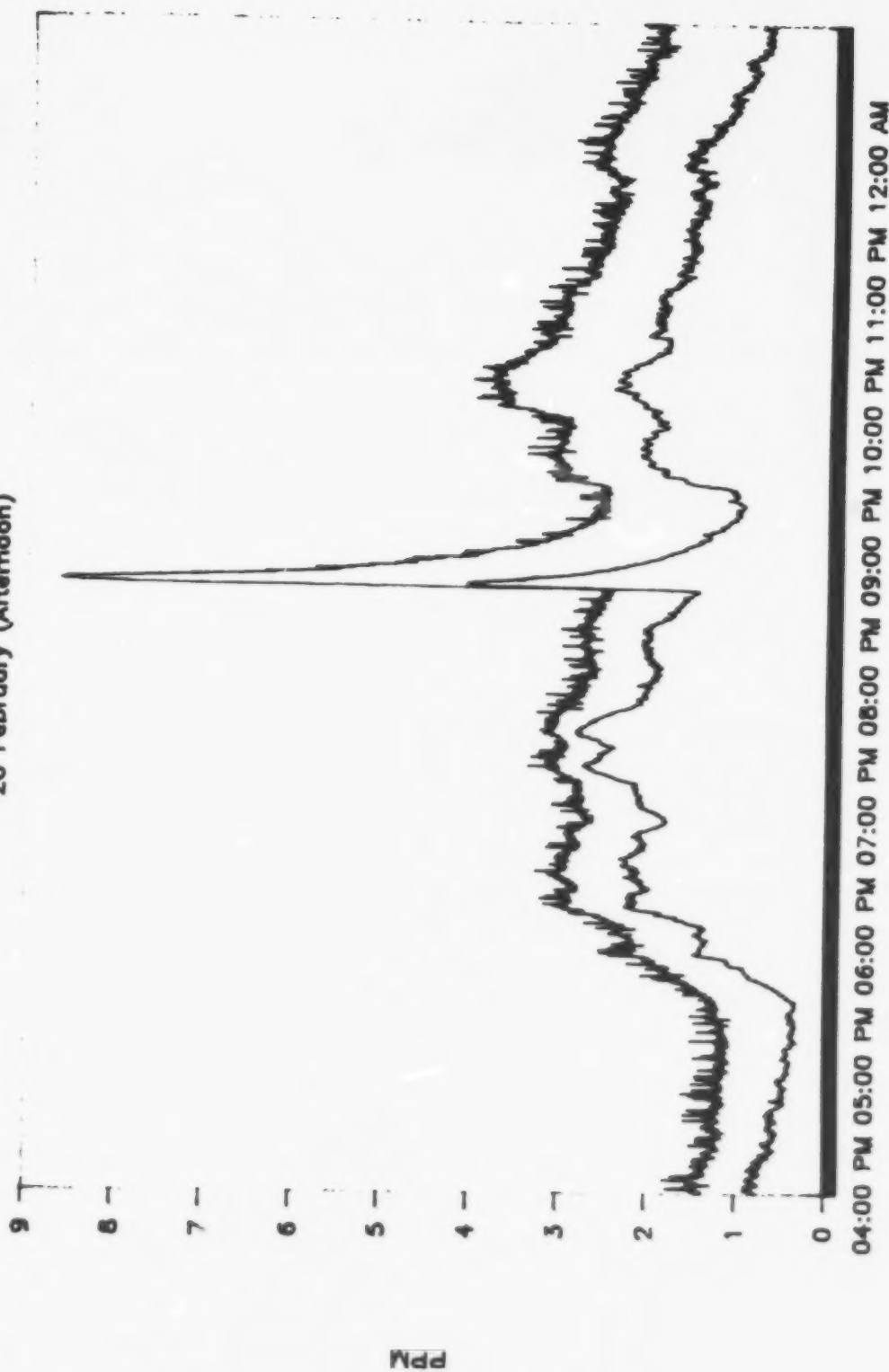
Figures 33 and 34A present more results from the V-4 monitoring.

7.3.5 Oil Mist Study

The purpose of this study was to evaluate the contribution of oil mist to organic particles in the mine atmosphere. The method to measure RCD is to hash samples of mine dust (gravimetric samples) in order to burn off all the organic material. The burned portion is considered to be the RCD fraction. If oil droplets released from the pneumatic equipment are present in significant numbers, they will contribute to the RCD fraction. This should be corrected since oil mist is far less toxic than RCD's.

CO and NO Emission, V--4 Exhaust (1000)

20 February (Afternoon)



Time Period
— CO
--- NO

FIGURE 30

CO and NO Emission, V-4 Exhaust

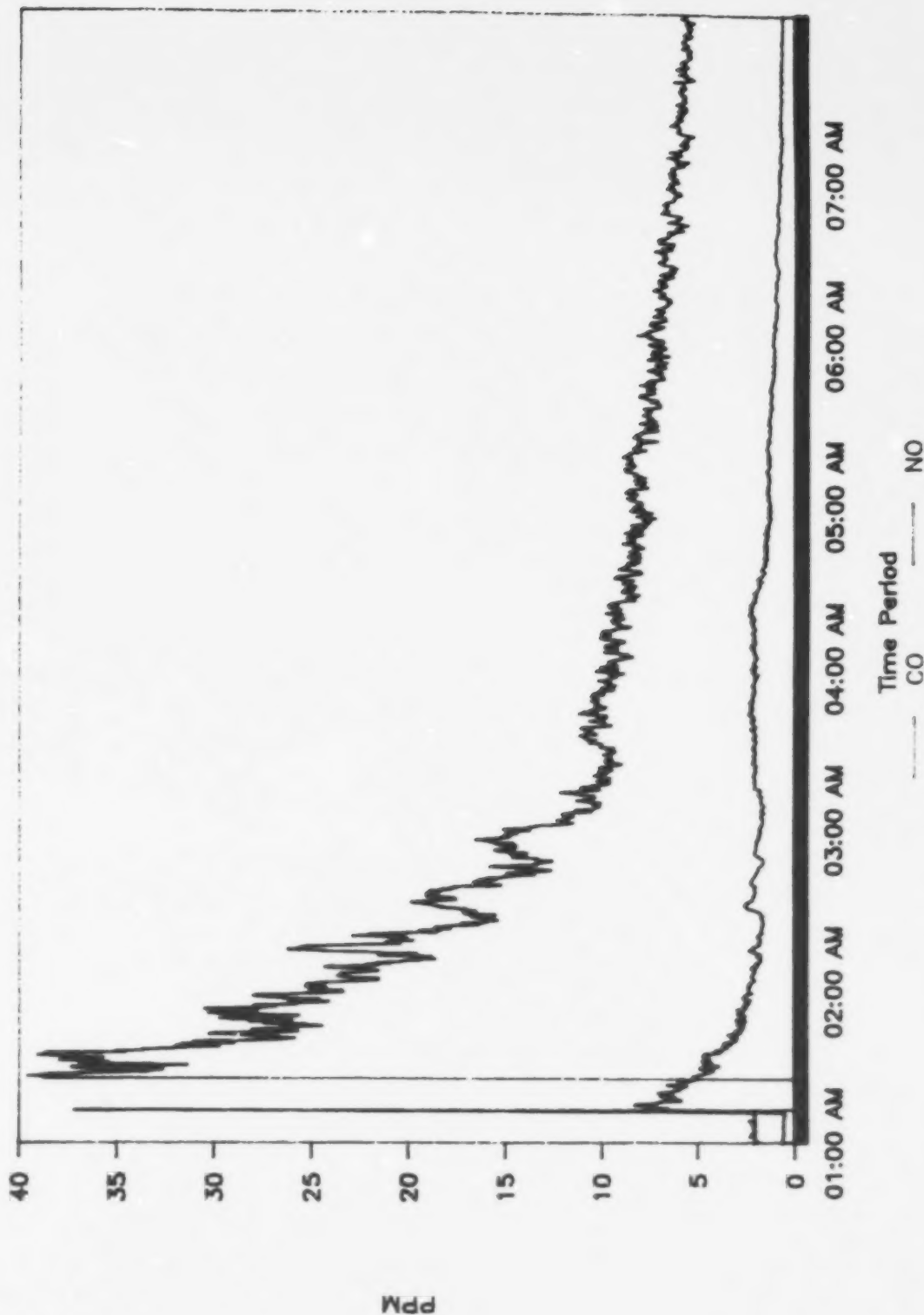
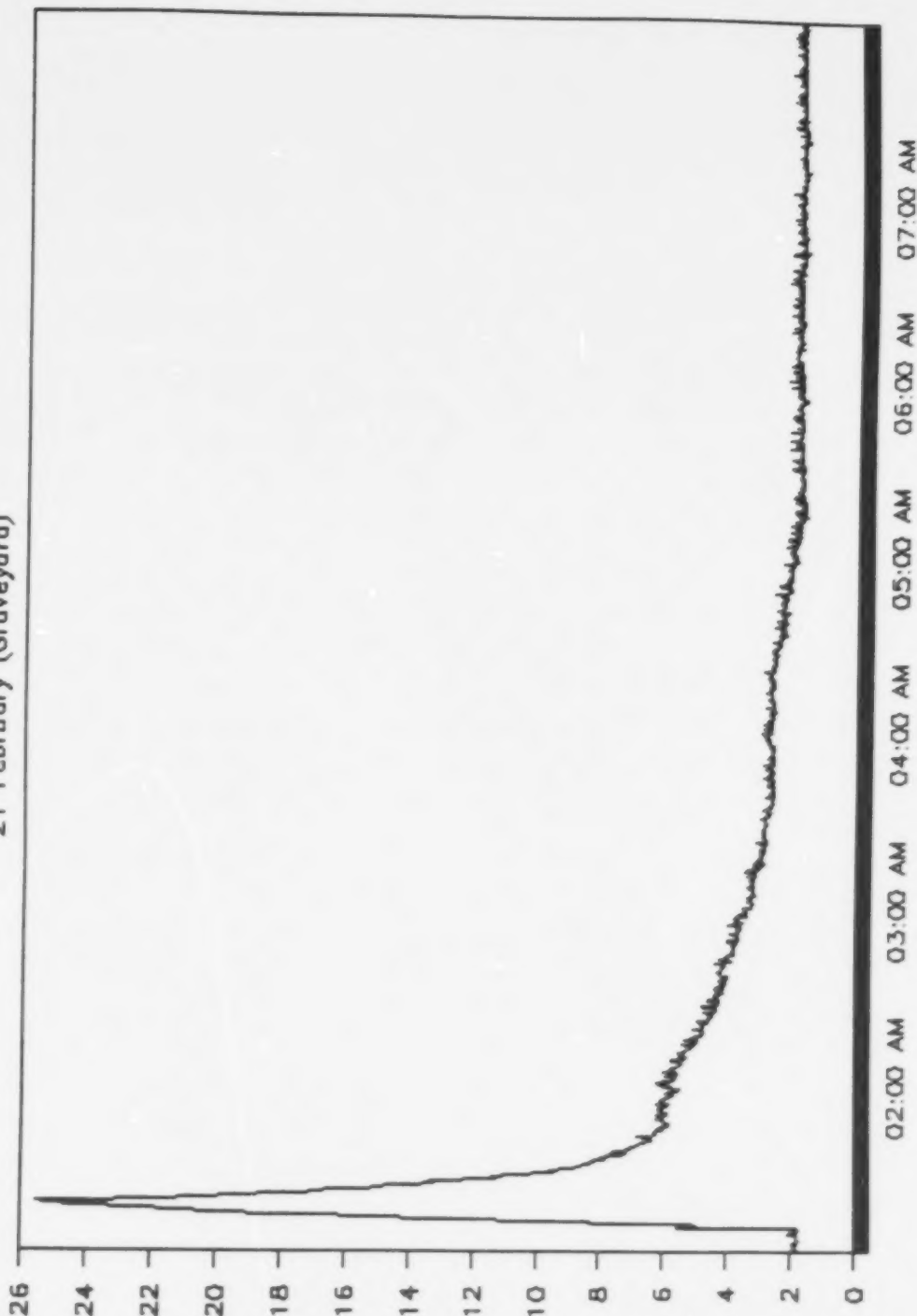


FIGURE 31

CO Emission, V-4 Exhaust (1000)

21 February (Graveyard)



Time period
— CO

FIGURE 32
(Traces include SO₂ Secondary Explosion)

CO and NO Emission, V-4 Exhaust

21 February (Day)

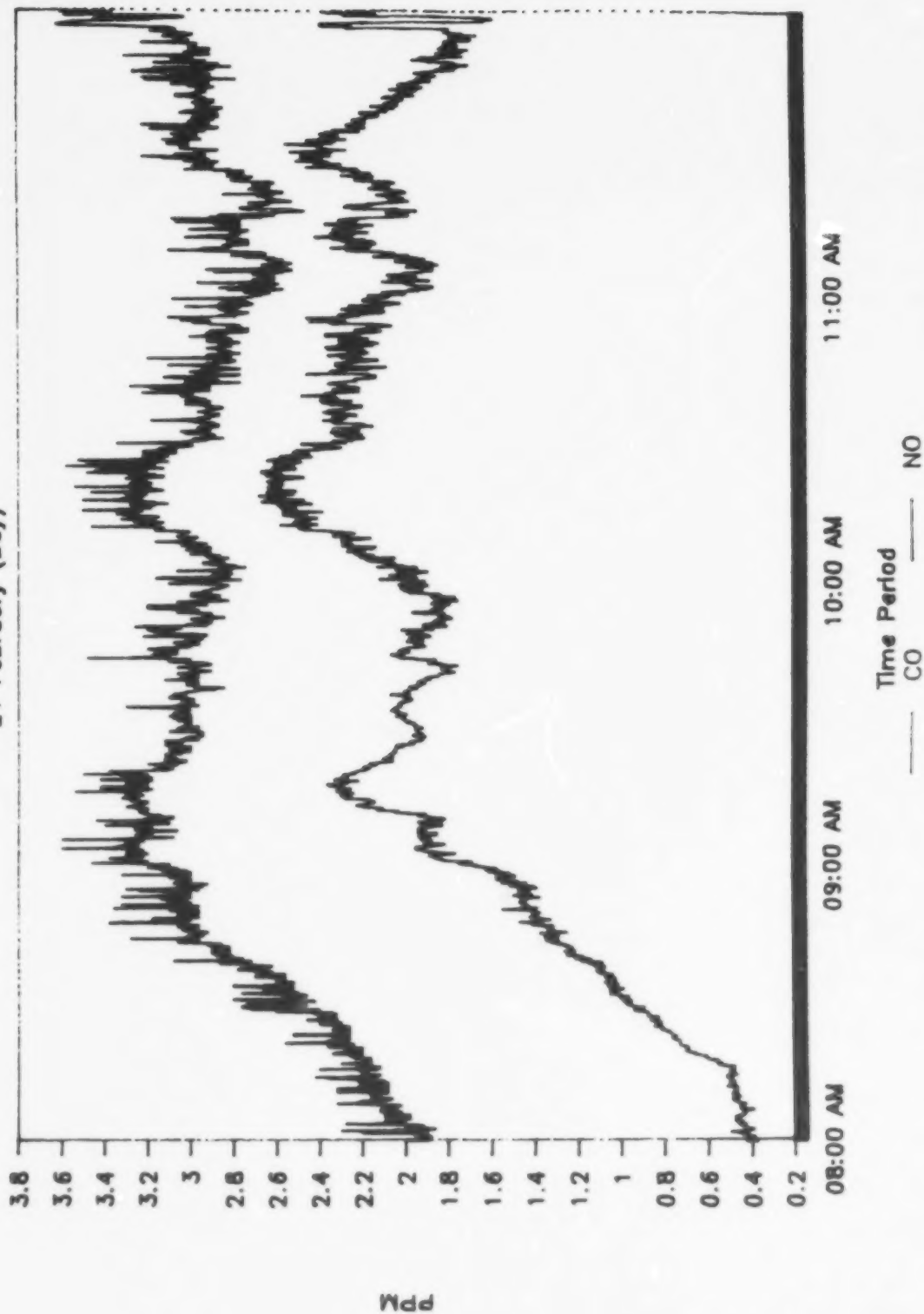
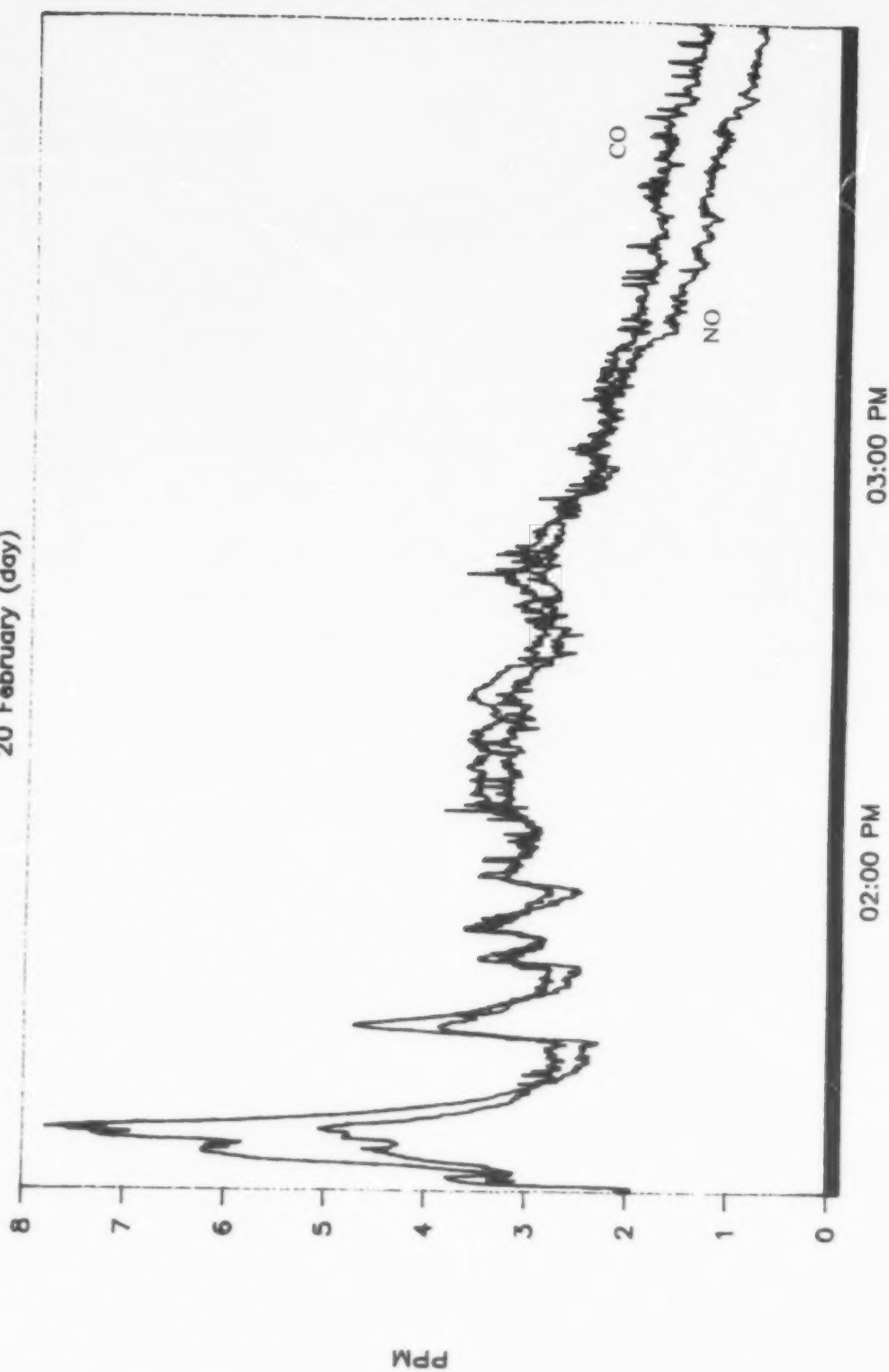


FIGURE 3.3

CO and NO Emission, V-4 Exhaust (10000)
20 February (day)



Time Period

FIGURE 34 A

To measure the oil mist in a sample, infrared spectroscopy techniques are used. First, a sample of oil is analyzed in the spectrum analyzer to produce a spectrum of the oil. Then the gravimetric sample acquired with a personal sampling pump in the mine is dissolved in alcohol and analyzed by the spectrum analyzer. The comparison of the oil spectrum and the sample spectrum allows for calculation of the weight of oil present in the sample (the absorbency at some specific frequency and constant path length is proportional to the concentration).

The tests were carried out by the Institute of Research in Health and Safety (IRSST) located in Montreal. For their tests, the minimum weight detectable is 50 ug, which corresponds to a minimum concentration of $.07 \text{ mg/m}^3$ (6 hours of sampling at 2 litres/min).

The samples were collected with Dupont personal sampling pumps (with and without cyclones) on the 1000 mL Sill exhaust drift, the No. 2 Sub exhaust drift, the V-4 exhaust and near an operating development drill.

The results are presented in Table VI. It appears from the results that drill oil mist contribution is eliminated by using cyclones. These results were confirmed in a separate study undertaken by CANMET and Noranda in 1986⁽¹¹⁾.

TABLE VI
TIME WEIGHTED SURVEYS FOR OIL MIST

Area	Cyclone	Sample Concentration (mg/m^3)	Oil Mist Concentration (mg/m^3)
1. 1000 mL Sill Exh	No	0.89	Undetected
2. 1000 mL Sill Exh	No	1.12	Undetected
3. 1000 mL Sill Exh	Yes	0.62	Undetected
4. No. 2 Sub Exh	No	0.31	Undetected
5. No. 2 Sub Exh	No	0.27	Undetected
6. No. 2 Sub Exh	Yes	0.20	Undetected
7. V-4 Exh	No	0.45	Undetected
8. V-4 Exh	No	0.28	Undetected
9. V-4 Exh	Yes	0.31	Undetected
10. Operat. Devel. Drill	No	1.21	0.2
11. Operat. Devel. Drill	No	1.07	0.35
12. Operat. Devel. Drill	Yes	0.83	Undetected

8. CONCLUSIONS OF PHASE I

The following observations can be made from the two surveys:

1. There is a linear correlation between CO/NO/NO₂/SO₂/CO₂ and RCD in underground mines. However, the linear correlation for CO, NO₂ and RCD is not clear from the surveys. There are no sensors manufactured for NO₂ and RCD contaminants which can adequately monitor the low levels present in underground mine atmospheres. The CO's lack of correlation, on the other hand, is probably due to the use of catalytic converters and, to a lesser extent, to propane burners.
2. The slope of the linear relation is greatly affected by factors such as the origin of the contaminants (blasting, burners and diesel), the diesel equipment and the exhaust conditioning system.
3. CO₂ is generated in relatively small levels by blasting, and in an area with moderate diesel activity the effect of blasting on CO₂ is barely detectable.
4. CO and NO are produced in great quantities during blasting.
5. The propane burners generate a lot of CO and CO₂. The amount produced will depend on propane : air ratio, air speed over the burners and exterior temperature. The levels can reach 9 ppm for CO and 1300 ppm for CO₂.
6. RCD is an important contaminant in the mine. Unfortunately, it cannot be monitored continuously. It is not affected by blasting or propane burners.
7. The oil mist test demonstrated that the RCD measurements, completed with the help of a gravimetric sampler and a cyclone, are probably not biased by oil mist. Although oil mist levels were detected near a development jumbo, none was detected with the cyclone installed (at the detectable level .07 mg/m³).

Since the results from the first survey indicated that the slope of the linear correlation appeared to be equipment specific, it was decided to verify in the second survey if it were possible to correlate Brake Horse Power generated or diesel fuel consumption with CO_2 produced on a level.

However, this proved to be impossible. Equipment moved in and out of the section frequently during the shift makes the task of monitoring the BHP or diesel fuel consumption in a specific section much too complex.

It is therefore doubtful that diesel equipment movement underground could ever be monitored successfully in order to adjust CO_2 : contaminants linear slopes.

It was hoped from this study to demonstrate the use of CO_2 as a control parameter for ventilation in a control system. The problem that now arises is that although a control system can be based on CO_2 , all contaminants will not be controlled strictly by such a system. As an example, CO could be controlled by keeping the CO_2 level at 800 ppm one day and 1100 ppm the next, due to a change in linear relation slope.

Even if the CO_2 is not a strict indicator of contaminant levels, the variation of CO_2 is in direct proportion to other contaminants. The sensors tested were also very sensitive to CO_2 and responded to changes within 5 seconds. This makes the CO_2 an ideal sensor for detecting sudden changes in pollution levels.

The Gastech CO_2 diffusion IR sensor is preferred to the Sieger model 5050 IR sensor. It is 25% less expensive and does not contain the sensitive microprocessing equipment that the Sieger contains.

The surveys also permitted identification of some excellent CO, NO and SO_2 sensors manufactured by Trolex in England based on conversation with NCB's scientists. They are compact, rugged, stable and very cheap. The NO cell is particularly sensitive, being able to detect levels below 1 ppm (see Figure 34B).

CO and NO Emission, 1000 Sub2 Exhaust

22 February (Afternoon)

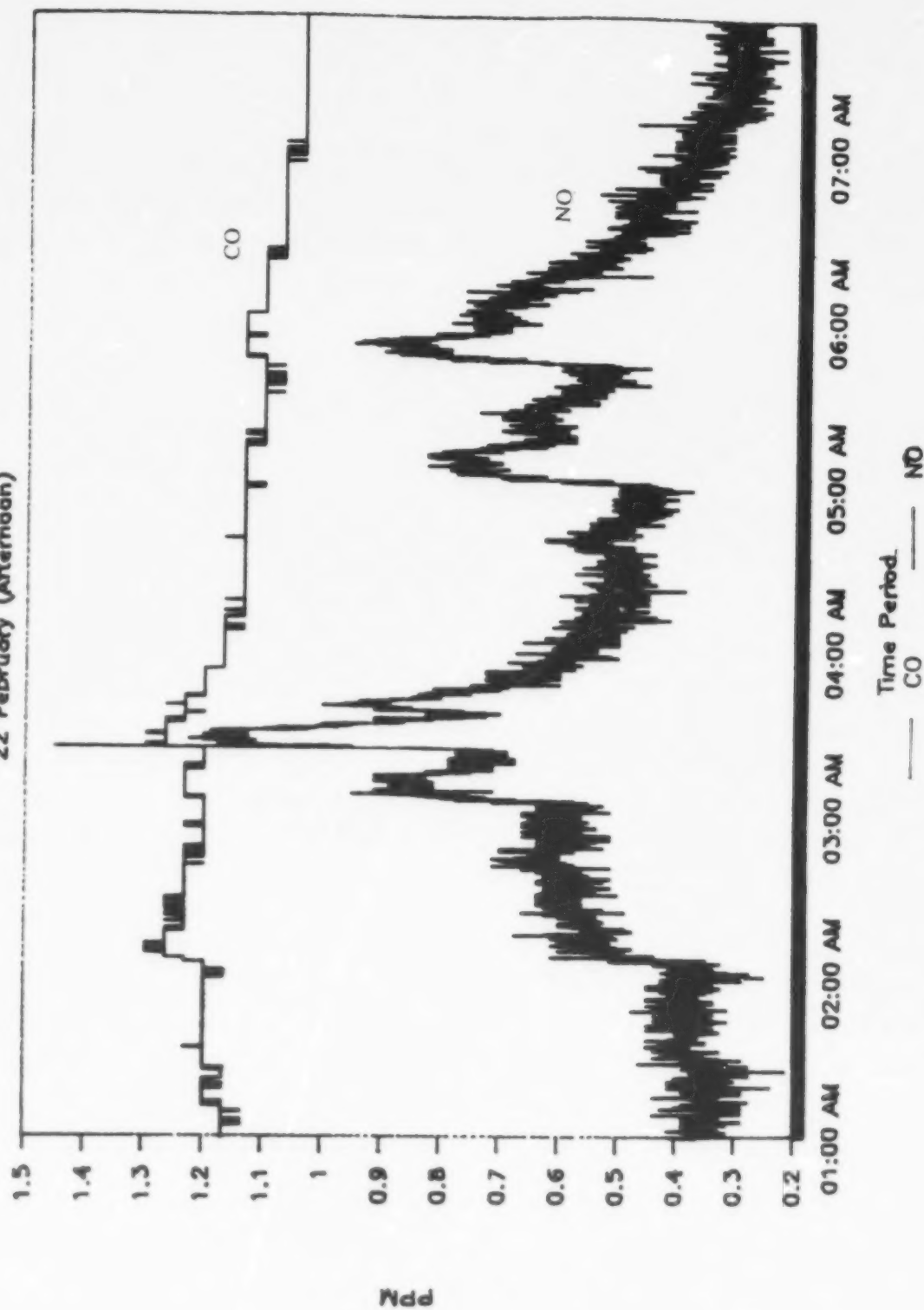


FIG. 34 B SENSITIVITY OF NO SENSOR

PHASE II
EVALUATION OF VENTILATION CONTROL OPTIONS

PHASE II - EVALUATION OF VENTILATION CONTROL OPTIONS

1. INTRODUCTION

In Phase I, it was shown that CO₂ can be used as a control parameter for mine ventilation since it is a good indicator of general pollution level. On the other hand, it was also shown that there are problems with using CO₂ with regards to propane burners and blasting. Also, CO₂, if used in a totally automated closed-loop control, will not provide adequate control for each specific contaminant since the characteristic slope will vary from level to level and from day to day.

In order to define how to use CO₂ sensors or any other sensors in a ventilation control system, the techniques of ventilation control must now be evaluated.

This is the subject of Phase II of the report. It describes the hardware, software, and transmission requirements for an automated ventilation system.

2. MINE VENTILATION CONTROL TECHNIQUES

Automation of mine ventilation systems has been studied by several mining companies and research organizations for the past 20 years. The approaches considered were numerous and they all required different levels of automation. In general, they can be divided into three categories:

- 1) Computer control of main intake and exhaust fans and level regulators or booster fans, based on air volume requirements for different shifts.
- 2) Computer control of all ventilation control elements based on gas sensors feedback from mine workings. Changes are predicted using a steady-state model and therefore based on time-averaged gas concentrations.
- 3) Computer control of all ventilation control elements based on gas sensors feedback. Changes are predicted using a dynamic model based on instantaneous gas concentrations. Ventilation under these conditions would be fluctuating at all times to maintain optimum conditions.

The full automation approach has been the subject of countless papers. Dr. Trutwin of the Polish Academy of Sciences, succeeded in modeling the dynamic behavior of simple ventilation systems using numerical modelling⁽¹²⁾, but the results also showed that unstable control arrangements could exist if air flow was automatically adjusted to maintain a fixed level of gas.

Furthermore, the mathematics involved in modelling a complex mine ventilation complex are so advanced that it has discouraged most researchers from pursuing the subject.

Experts now agree⁽¹³⁾ that ventilation control will be most successful by using the first two techniques described above. At present, the only mine-wide control systems in existence are systems based on the first technique described. The main reason why there is no installed system based on pollution feedback, is that up to three years ago, there were no reliable gas sensors manufactured for underground mines.

A good example of the application of the first technique can be found in Finland⁽¹⁴⁾. In 1969 the Outokumpu company began to develop a fully automated control system at its Pyhasalmi mine. An effective mine ventilation system was necessary to control the sulphur dioxide generated by sulphur dust explosions and provide flexible ventilation that could be readjusted every shift if required. A three-phase program was employed in the development of the system. The first task was to construct a mathematical ventilation model for the mine. The model was used to predict the behavior of natural ventilation and analyze the volume and directional instability of the system under various disturbances (such as a door left open). This step was very important in order to optimize the installation of regulators and fans and avoid the possibility of reaching unstable conditions. The model was not use in the actual control but became a very useful tool for ventilation planning later on. The second phase of the program involved installing, testing and modifying the ventilation equipment and controls, and operating the system manually to check the conformity with the model. The third phase consisted of automation of the ventilation system by installing a process computer for control. This work included the planning and programming of the control strategies, and the various ventilation situations as described by the mine operating activities.

The entire Outokumpu project took four years to complete. A major portion of this time was required to complete phase two (manual control). The regulators' performance and reliability were very poor at first and intensive field work was required to troubleshoot. The system as it is today requires the mine ventilation engineer to define the fresh air requirements in the mine

during working hours. The computer contains six possible ventilation scenarios during working hours as well as situations for week-end, night, and postblasting. The situation is chosen by the computer based on the amount of fresh air required by each workings as determined by the ventilation engineer. During nights and week-ends the ventilation program is automatic and does not require the input of the ventilation engineer unless overtime is scheduled. During blasting hours, all ventilation doors are opened to clear gases rapidly. The state of the general ventilation is measured by means of nine air flow meters as well as several air flow direction sensors, and three temperature probe. The ventilation computer compares the measured state to the currently prescribed ventilation situation and removes deviations through adjustment of the air flows by means of the ventilation doors and the main fans.

The system at Pyhasalmi mine has reduced heating energy for ventilation air by an average of 25% and the need of total energy for main fans by an average of 35%. Although the present system is controlled and regulated by airflow measurements, the final aim is to control and regulate the ventilation by CO₂ analysis and use CO and SO₂ sensors to identify fires and secondary dust explosions.

The approach used by Outokumpu has also been applied in China and Belgium with similar success^(15,16).

3. PROPOSED CONTROL STRATEGY FOR BMS-M

3.1 Control of Auxiliary Ventilating Fans

BMS-M initiated the automation of their ventilation system in 1984 with the installation of on/off control for their auxiliary fans. Auxiliary fans are used to ventilate dead-end drifts and their operation does not affect the rest of the ventilation system. Thus they can be turned off when not in use, minimizing power costs.

Several countries have used on/off control to automate the auxiliary fans in their mines. The method used is to hard-wire every point to a central computer. BMS-M has come up with the unique idea of using Power Line Carrier (PLC) technology to communicate between the computer and the fans. The technique modulates the transmission signal over existing electrical cable. The PLC enables easy installation of fan control without the heavy costs associated with point to point wiring.

The technique has only been implemented on a trial basis using a small number of fans. These fans operate by a simple schedule. At the end of each shift, all the fans are turned off. To ensure complete removal of blast gases, the fans are turned on for one half hour immediately following the blast. The fan in the active area is turned on manually by the workers as they enter the area.

Thirteen fans were controlled in this way for a period of two months. Several mechanical problems were encountered during this time which had to do with poor workmanship of the PLC product. Nonetheless savings of \$5000 over this period were realized and the mechanical problems were for the most part overcome.

Mr. Matthew Laplante of BMS-M has proposed to gradually expand the system to all the mine in 1989 (approximately 200 fans). First a trial on an entire level (and its sublevels) will be carried out for a period of 2-3 months (20-30 fans).

NTC has cooperated with Matthew Laplante in identifying a software package which would manage the scheduling of auxiliary fans and the monitoring and control of the main ventilation system. The software was purchased by NTC in January and is ready for testing.

3.2 Control of the Main Ventilation Network

As was explained in the earlier section, there are two techniques which can be successfully used to control ventilation. Ideally, an automatic mine ventilation system would be based on closed-loop control. Air quality sensors would pinpoint locations with inadequate ventilation, and appropriate control equipment would then adjust the air flows accordingly. No human intervention would be required for normal operation.

The benefits of such a system would be considerable. First, an excellent standard of air quality would be maintained at all times throughout the mine. At the same time, there would be no excess ventilation, so power costs for the fans and propane heaters would be minimized.

The cost of installing the air quality sensors could however be prohibitive because there are at least six pollutants to be controlled underground. This is why NTC proposed to use CO₂ as the main control parameter for ventilation. Tests undertaken at Brunswick demonstrate that this

could be a feasible approach since CO_2 is a good indicator of the general level of pollution in a diesel intensive environment. The tests also demonstrated that NO sensors could also be a feasible approach.

Such a feedback control will still inevitably be complex. This form of automation has never been implemented in a mine and there are numerous problems to be addressed. The sensors must be installed in strategic locations and a thorough understanding of the network must be developed to interpret the sensor readings.

An alternative is to initially install an open-loop system similar to the Pyhasalmi mine system. Open-loop control operates by setting the system to some predetermined state and in the context of mine ventilation, it would provide the flexibility to fine-tune the air flows to suit changing conditions. This flexibility will lead to better air quality at a lower energy cost. However, regardless of which system (open or closed loop) is installed, the final control elements and the telemetry system which will control the ventilation will be the same. The following pages describe the design selected for BMS-M.

3.3 Control System Design

Air in a mine flows from regions of high pressure to regions of low pressure. This pressure differential at BMS-M is created by the main surface fans, and slightly augmented by underground booster fans. Regulating doors and more booster fans modify the distribution of this air throughout the different levels and sub-levels. Sets of double doors or single doors prevent the air from short-circuiting to No's 2 and 3 shafts, and small free-standing fans re-distribute the air in the workings.

These components must assume particular settings for a given distribution of air. Therefore, in order to control the quantity and distribution of air flow, fans and regulating doors must be automated for remote control.

The branches of a mine network are inter-dependent; that is, any modification to the volume flowing through one level will immediately affect the pressure and volume characteristics of all the other levels. Thus, the proper control setting of each component depends on the settings of all the others. For this reason, the control must be achieved by one central computer, and not a

distributed system where independent computers or programmable logic controllers control parts of the network. A central computer would take the desired state of the ventilation and determine the appropriate control setting for each component.

3.3.1 Central Computer

The central computer will be a personal computer using an 80286 microprocessor. The choice of a personal computer is based on the large selection of control software available for PCs and the limited amount of mathematical complexity required of the computer.

The software will be a combination of an off-the-shelf product and NTC-developed program code. An evaluation of the monitoring and control software available for PCs was done by NTC, and the FIX program by Intellution was chosen based on its open architecture design and ability to communicate with several types of input/output devices simultaneously. A description of the fix is provided in Appendix H.

3.3.2 Communication System

Communication between the surface fan controllers and the central computer will be through a dedicated pair of wires and I/O device such as the Opto22 by Optomux or the Dupline 128 by Electromatic.

For underground communication the system will be more complex. The computer will first communicate with industrial personal computers (made to stand harsh environment and continuing battery back-up) on the main levels using existing twisted pair cables. Each underground PC will then communicate with the control elements associated with it via the same power line carrier (PLC) system already used for on/off control of auxiliary fans. Figure 35 illustrates how the entire communication system will be organized. See Appendix B for more information on the communication system.

The underground PCs will have a minimum of supervisory control to do as most of the control will be provided by the central computer. Their main function will be to provide a fail-safe state in case of communication malfunction with the surface computer.

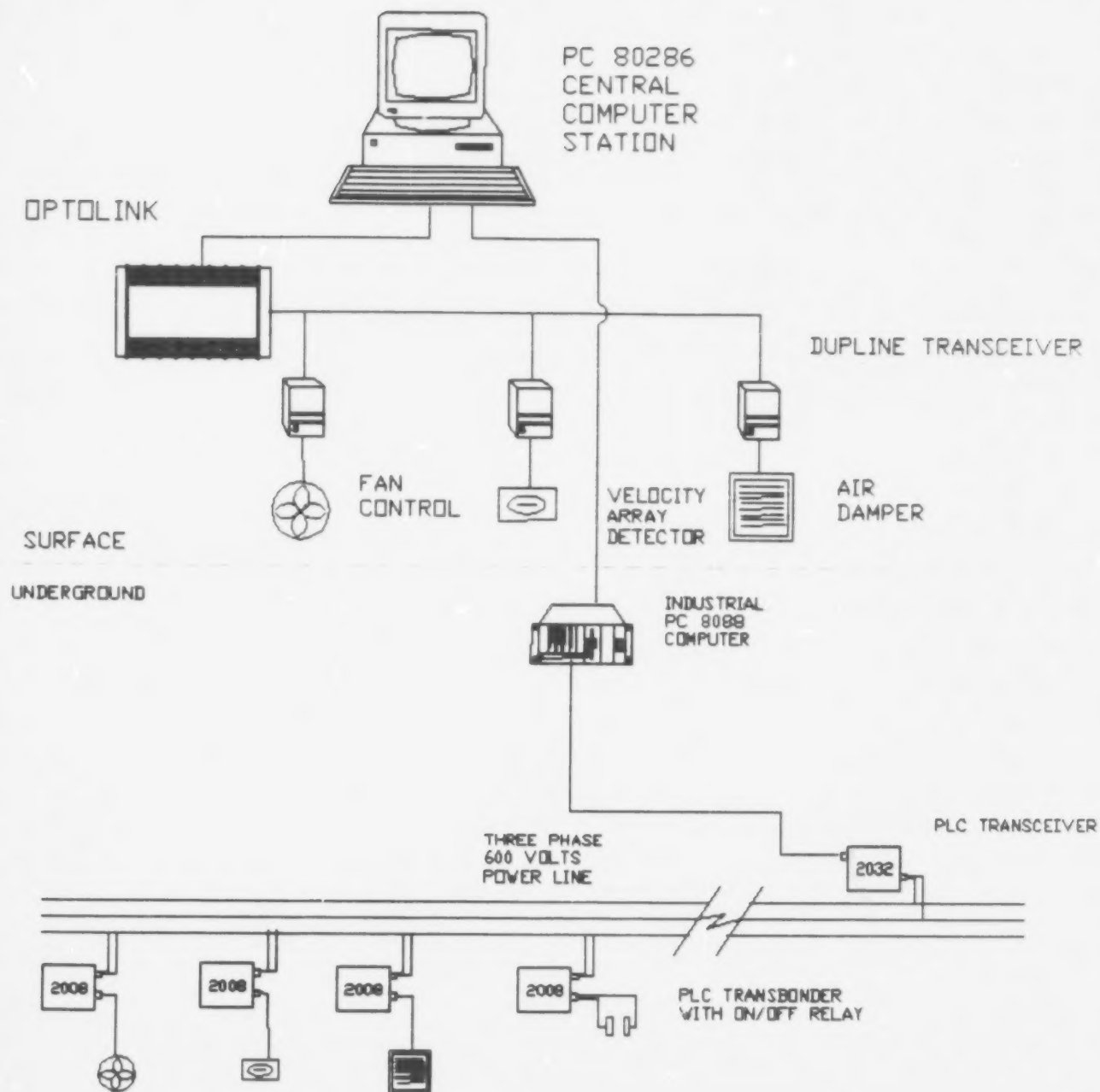


FIG. 35 COMMUNICATION SYSTEM DESIGN

3.3.3 Final Control Elements

The final control element will have to be selected to accommodate for maximum and minimum flow variations since this device will be doing the actual controlling action of the manipulated variable, i.e. the airflow. Furthermore, it should be well designed mechanically so that it will be positioned easily and consistently by the signal from the central computer.

3.3.3.1 Fan Control

There are three methods of controlling fans: adjustable dampers, variable pitch control and variable speed control.

Adjustable dampers are a set of remote controlled regulators placed in front of the fans which can reduce the airflow by increasing the resistance of the fan. Although they provide an inexpensive way of reducing the airflow, they are very inefficient and do not reduce the energy requirement significantly.

A variable pitch-in-motion fan is an axial flow fan, with a variable blade pitch angle while the fan is in operation. It allows the air volume and/or pressure produced by the fan to be adjusted easily and smoothly without losses in efficiency.

Figure 36 shows an example of the air performance data of such a variable pitch-in-motion fan. It illustrates that every pitch-angle value has its own corresponding performance curve; i.e. by changing the pitch angle we can alter the properties of the fan. With lesser pitch angle the fan represents one chosen for a small air volume, and with greater pitch angle one chosen for large air volumes. The maximum air volume naturally depends, besides pitch angle (max. $\sim 40^\circ$), on the size, rpm-value and number of blades of the fan.

The air performance data with corresponding energy requirements for variable pitch-in-motion fans are presented in Figures 37. The figure shows the power input of the fan when the system follows a normal static-pressure curve. When the air volume is reduced by 50% (from 40 to 20 m³/s), the power input drops to 42% of the initial value (from 30 to 21 kW).

REV/MIN. 870
No. of OF BLADES 12

FAN DIAM. 1800mm
FAN CODE 180JGS0-8-12
FREQUENCY 60Hz

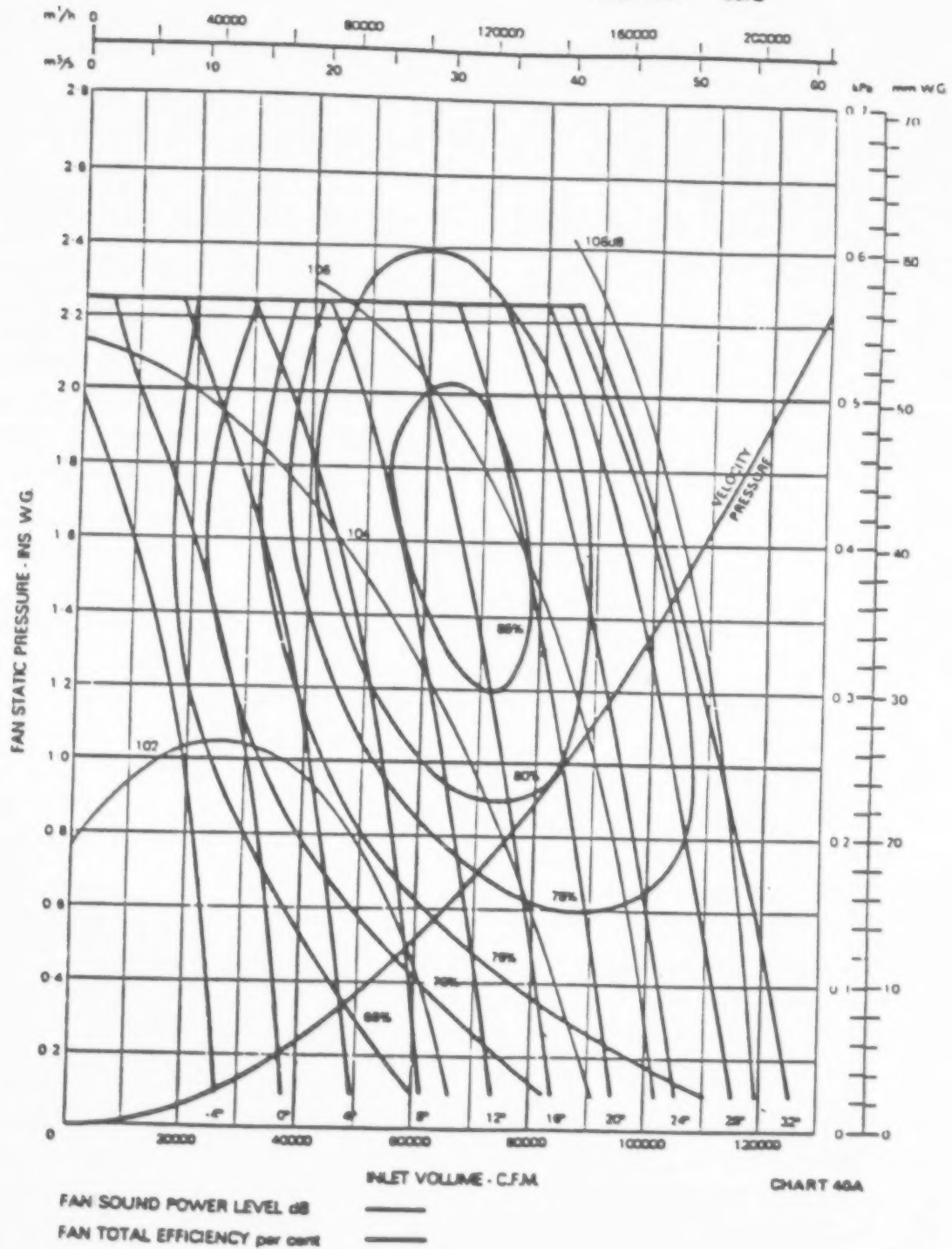


FIG. 36 AIR PERFORMANCE DATA OF
VARIABLE PITCH-IN-MOTION FAN

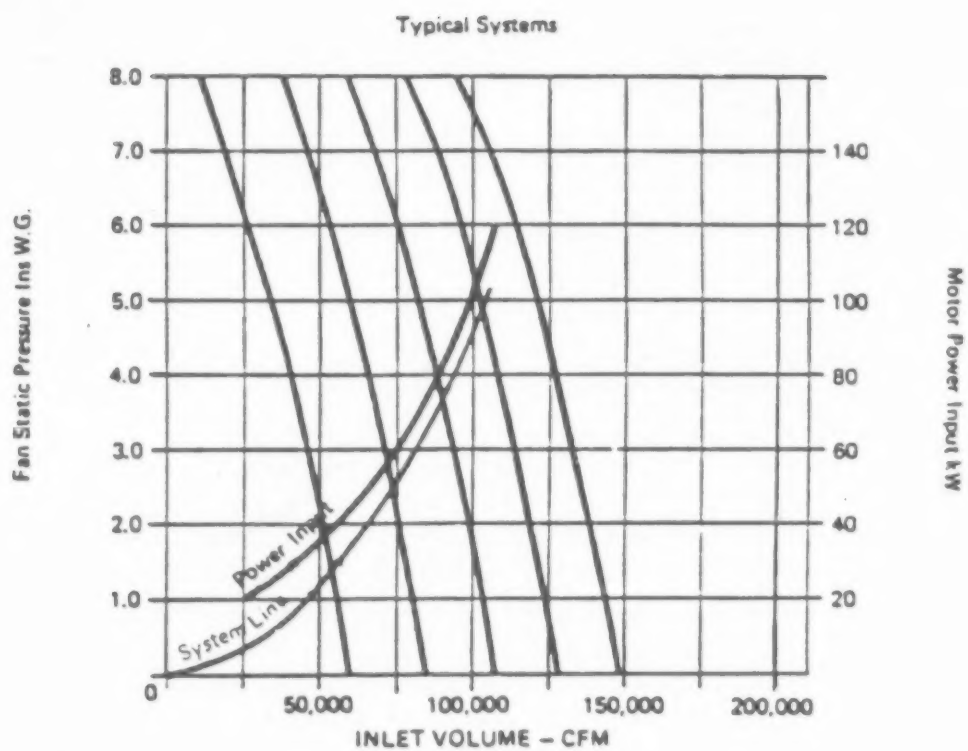


FIG. 37 AIR PERFORMANCE DATA WITH
CORRESPONDING ENERGY REQUIREMENTS

The most popular mechanism to adjust the pitch angle is a diaphragm assembly in the hub which is controlled by a metered air supply. The air supply is generated by a small compressor mounted on the outside of the fan casing. The air pressure supplied is dictated by the control signal from the controller, through an adjustable valve. Figure 38 illustrates a Woods Colchester Ltd, Varofoil fan control hub.

Variable speed controllers are more sophisticated in design and the types of controllers will vary according to motor types. For a wound rotor motor, a slip-energy recovery (SER) drive system is used.

The SER converts rotor slip-ring voltage to DC by means of a rectifier and feeds this current via a smoothing reactor to a line-commutated inverter connected to the input power supply. The inverter, controlled by the system control logic, converts DC from the rotor rectifier to an alternative current compatible with the input power supply. At the same time, the inverter controls the rotor voltage and current to provide the desired motor operating speed. The controller recovers 97% of the slip energy generated in the motor rotor whenever the drive operates at less than its rated speed. Fig. 39 illustrates the controller schematic as well as a power consumption curve comparison for a fixed speed motor with adjustable dampers and an SER.

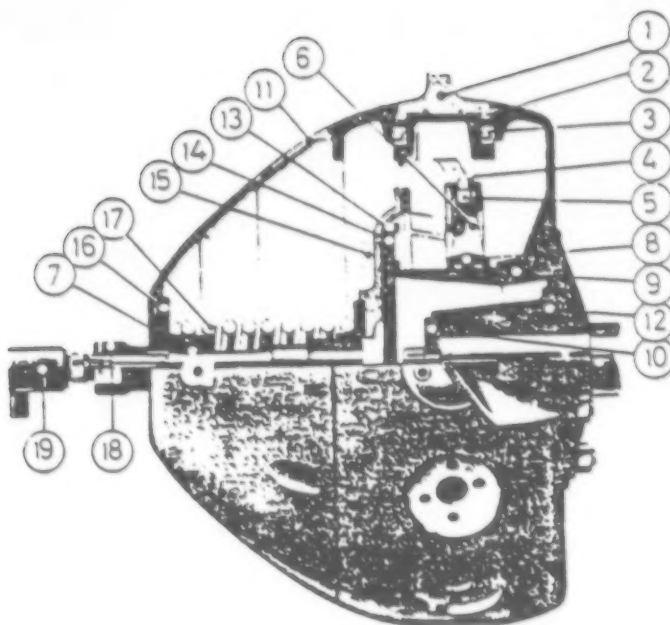
For squirrel-cage type motors, AC drivers which produce a sine coded pulse width modulation of the input voltage from zero to maximum can be used. These drivers are slightly less efficient than the SER drive (95% vs 97%).

BMS-M's main fans are equipped with both wound rotor and squirrel cage motors.

To establish the relationship between speed and air volume, the following fan law must be used :

$$Q = k n D^3 \text{ where } k = \text{constant}$$

n	=	rotational speed
D	=	fan diameter



500/710mm VP HUB

key

1. Blades
2. Retaining Plates
3. Ball Bearings
4. Actuator Arms
5. Cam Followers
6. Actuator Wheel
7. Bearing for Actuator Wheel-Front
8. Bearing for Actuator Wheel-Rear
9. Hub
10. Hub Retaining Plate
11. End Cover
12. Hub Adaptor
13. Diaphragm Reaction Plate
15. Diaphragm Housing Assembly
16. Front Bearing Housing
17. Spring
18. Stop Nut
19. Rotary Seal

FIG. 38 WOOD COLCHESTER VAROFOIL CONTROL HUB.

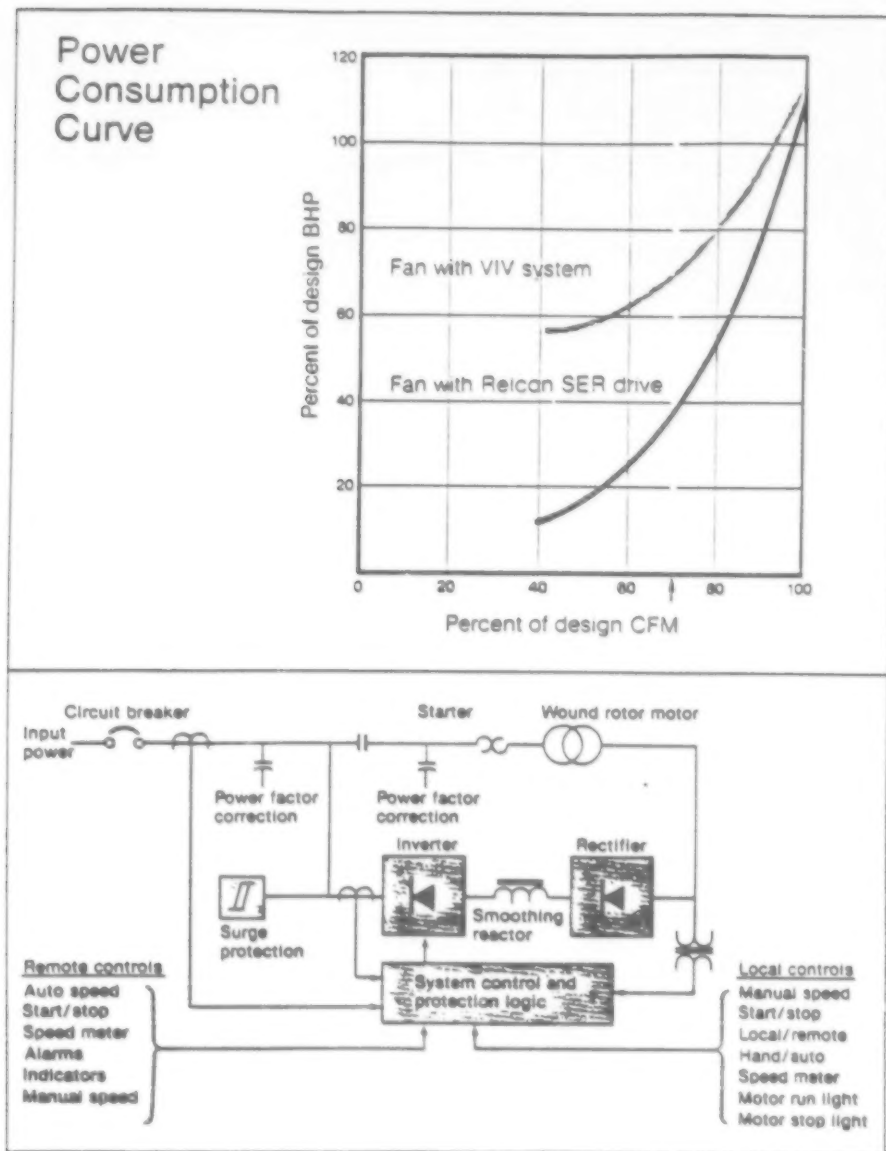


FIG. 39 POWER CONSUMPTION CURVE
AND SCHEMATIC OF SER.

It can be seen that for any type of drivers (SER or AC), the air quantity through the fan is a direct function of its speed. Regardless of this fact, the system is nonlinear. The nonlinearity is caused by two factors; first by the inherited nonlinear characteristics of the power control element and, second, by the power-speed characteristics of the power-motor combination.

It should also be noted that, unlike variable pitch fans which can reduce flow to 10% of maximum, variable speed fans are not recommended for less than 40% of maximum.

3.3.3.2 Main Surface Fans Control

Both variable speed and variable pitch can be used to control the surface fans, but the speed controllers are slightly less efficient at full capacity. The speed controllers are preferable, however, since they are considerably less expensive for the HP rating of these fans.

An SER drive will be used for the V-4 and V-5 fans and an AC drive will be used for the V-2 and V-3 fans. See Appendix C for further information.

3.3.3.3 Booster Fans

Booster fans installed underground must be regulated in order to ensure that they remain compatible with the pressure and volume conditions established by the main fans, otherwise, recirculation or unstable conditions could occur. Regulation of these fans will also provide power savings and improved control over airflow.

As with the main surface fans, variable speed control and variable pitch control are both possible. However, variable speed controllers are large and cumbersome, and not suited for underground applications. In addition, variable pitch-in-motion controllers are less expensive for the horsepower of booster fans. Variable pitch is therefore the optimal choice for this application. See Appendix D for details.

3.3.3.4 Propane Burners Control

In the winter, incoming air is heated by propane burners to prevent ice from building up in the vent raises and to provide a comfortable working environment. The number of burners operated is determined by the outside air temperature. The control is achieved by an automated close circuit incorporating an outside thermocouple arrangement.

In order to have an efficient flame which produces minimum contaminants, it is necessary to control the position of dampers at the inlet to the burners. The objective is to keep the air velocity over the burners between 2700 and 3000 ft/min.

At present, this is done manually, as the air velocity is fairly constant at all times. In an automated system, the dampers will have to be controlled automatically by a close loop circuit incorporating a velocity monitoring system (described in Section 3.3.4).

3.3.3.5 Regulating Doors

Regulating doors are used throughout the mine to regulate the flow of air. At the main ventilation raises, they are used to modify the quantity of air flowing through each level. There are two types of regulating doors currently used: slide-type and hinge-type.

The hinge-type doors are the most common doors at BMS-M. They are made of two wooden halves hinged to opposites sides of the drift. Where pressures are very high, a double set of doors are used to form a lock.

The hinge-type doors have been replaced by slide-type doors in areas of extreme vibration. These vibrations can be due to the turbulent flow of air at high static pressure across the doors or to the extreme concussion wave created by blasting in the vicinity.

The slide-type doors consist of large wooden beams held in place by steel rails. The volume required is controlled by manually adding or removing beams.

In order to automate the hinge-type doors, mechanical linear actuators could be simply installed on the doors. Two such actuators have recently been installed at BMS-M to facilitate the manual opening of certain doors.

For the slide-type doors, the doors will have to be completely removed and new ones installed. There are two possible choices of replacement and each have inherent advantages and disadvantages. Rolling type steel doors can be installed. They were the type used at the Pyhasalmi mine and they are also being installed at Gaspe and Ansil mine. They are rugged and require little maintenance but are more affected by rock creep or obstructions than hinge-type doors. Another alternative is to install a louvre type regulator. This is a door containing parallel slanted slats which can be controlled by a mechanical actuator. It has been tested in Poland and Germany with limited success because of the maintenance problems caused by the many moving parts.

Their advantages over roll-type doors is the linearity of the opening vs airflow curve for this type of regulator. This is due to the minimum flow disturbance caused by such regulator design. For a rolling-type door, this curve can be approximated from the fluid mechanics equation for an orifice in a pipe(17):

$$Q = CA_o \sqrt{\frac{2\Delta p}{\rho}}$$

where

Q is the flow

o is the area of the opening

Ap is the pressure drop across the regulator

ρ is the density of the fluid

C is given in Figure 40

The effective flow-position (opening) characteristics for a rolling or sliding door using this equation are shown in Figure 41 for different constant pressure drop across the regulator².

2. Note that the pressure drop across the regulator will not be constant in a ventilation network. The actual flow-position behaviour of the regulator is therefore more complicated than that given by the approximated orifice equation and cannot be given by a single equation since the flow vs pressure of the network is nonlinear.

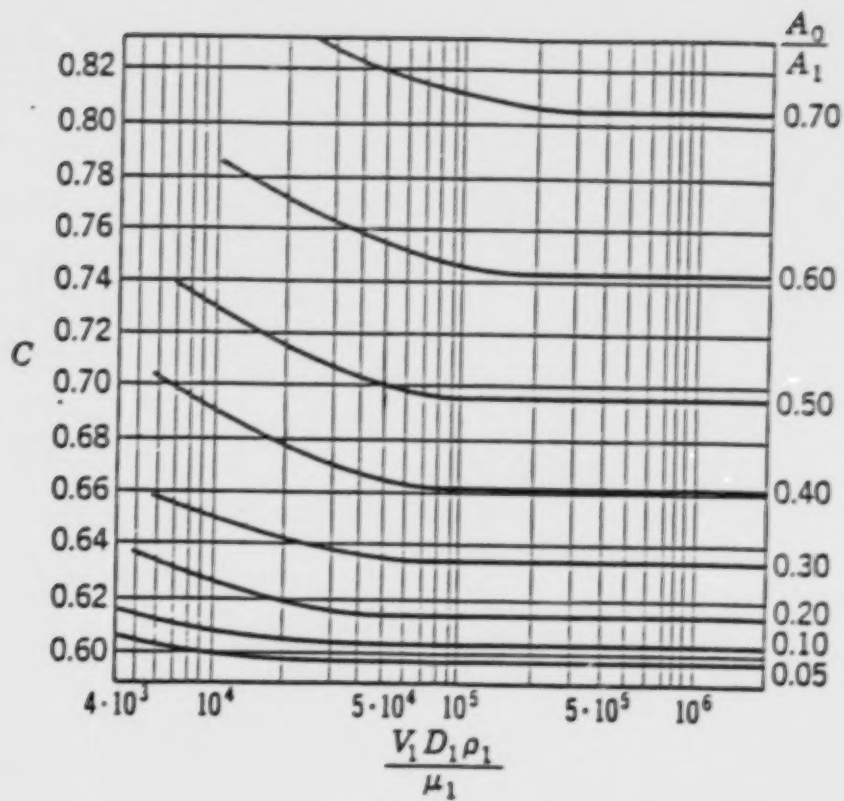


FIG. 40 VDI ORIFICE AND DISCHARGE COEFFICIENTS (ref.16).

Air Velocity vs Opening

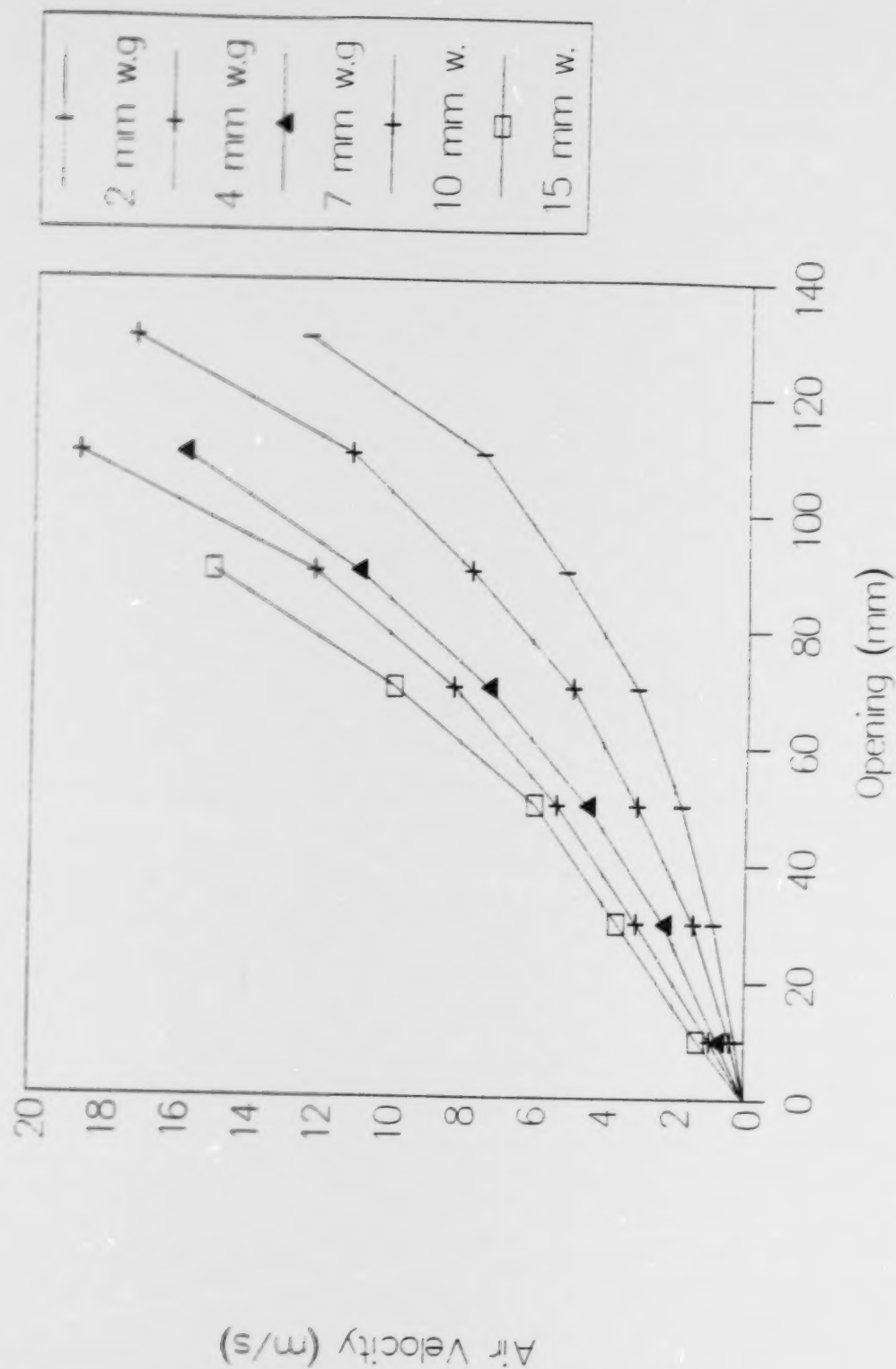


FIG. 41 FLOW POSITION CHARACTERISTICS.

Since this relationship is nonlinear, there will be a range of door positions where the flow is very sensitive to small disturbances in door positions. The louvre type regulator does not have this problem.

Despite this adverse opening vs flow profile, NTC recommends the use of roll-type doors over louvre-type regulators because these doors are being successfully manufactured specifically for underground mining applications (see Appendix E for details).

3.3.3.6 Position Encoder Specification

The encoder provided by M & I Door Systems Ltd., is an 8-bit resolution in 360 degree rotation. The encoder can be installed on the motor to provide a 1/2" precision on the door position or on the door itself to provide a 1/8" - 1/4" precision. The precision required must be evaluated through full-scale testing.

3.3.4 Airflow Measurement

The quality of control obtained with the system depends essentially on the sensitivity, consistency and speed of response of the feed-back element (i.e., the air velocity transducer). Equally important is that such a transducer should not be affected by dust and moisture, be reasonably robust and be insensitive to changes in the ambient air temperature and pressure.

The instruments commercially available can either be of the vane anemometer, hot-wire anemometer or vortex shedding types. Vortex shedding is the only type meeting all the above requirements. However, it has one drawback, and that is the problem of site calibration. The principle of the vortex-shedding anemometer is the measurement of the vortices formed by the impact of the airflow on an obstacle. These vortices are site and position specific, so the instrument must be calibrated carefully when installed, and protected from impact which might alter its position.

Airflow will have to be monitored at the surface fans and near the regulators underground.

For the surface installation, the fan ducting or drift is very short in distance and contains sharp bends. The air quantity is so concentrated in this way that the air velocity becomes very high, and the airflow in the fan duct is very turbulent. Therefore, no single anemometer is satisfactory because there is too much difference between the measured value and the actual value of air quantity. The alternative is to use an array of anemometers (see Appendix F). For underground use, a single point anemometer will be adequate (see Appendix F).

Poland and China have both designed new sensors based on ultrasonic techniques. These sensors are not manufactured at present. NTC will investigate this approach further.

3.4 Control Considerations

Before ventilation control alternatives can be presented, traditional control techniques applied to ventilation control must first be examined.

Since the variable to control in ventilation is the airflow and the control elements are the regulators and adjustable fans, the traditional control approach would be to install an airflow monitor near each final control element and form a closed loop control system between the two (see Figure 42). The desired airflow could be a calculated value from actual contaminant data or a requirement based on possible diesel distribution. The simplest mode of control of the regulating element would be proportional. As the name of this mode signifies, the output of the controller is directly proportional to the error between desired and measured flow. Generally the control action achieved with this mode of control is characterized by a considerable steady-state error. Elimination of this phenomenon may be obtained by introducing other modes of control into the controller, namely derivative or integral modes or a combination of the three. A combination of proportional plus integral (PI) action would remove the steady-state error, but otherwise have little effect on the system response, which is greatly influenced by the small time lags involved in the flow process. On the other hand, proportional plus derivative (PD) action would enhance the system stability and hence permit increase of controller sensitivity, and consequent increase the speed of response. In order to speed up the system response, and at the same time eliminate steady-state error, it is therefore advantageous to use the combination of proportional, integral and derivative control actions (PID).

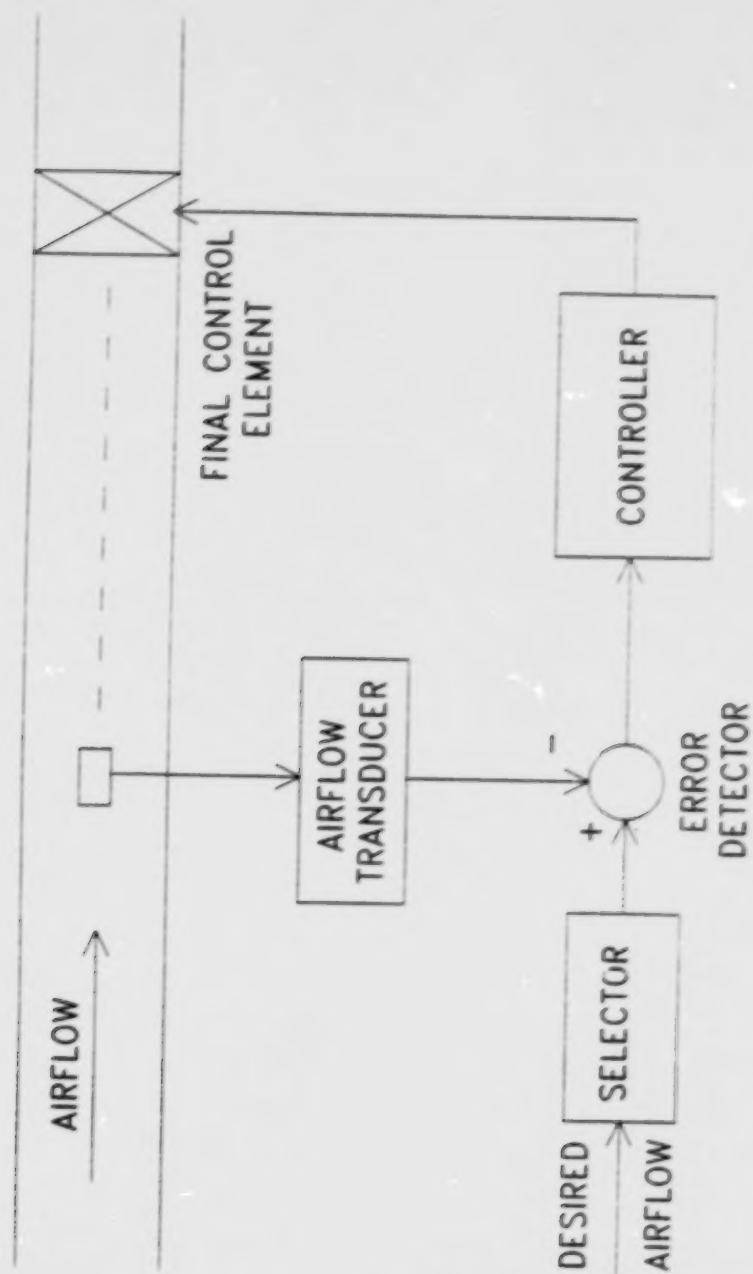


FIG. 42 CLOSED-LOOP REGULATOR CONTROL

Mahdi and McPherson (18) simulated the control of a single regulator based on the PID technique. Figure 43 demonstrates the response obtained under a sudden change in airway resistance. The response is very good.

The problem with the traditional approach is that a ventilation network is entirely interconnected. From a controlled engineering point of view, the network represents a multi-variable nonlinear system. A change in the airflow of any particular working may have some effect, not only on adjacent workings but on the entire network. Therefore, a nonlinear model of the complete network must be used to adjust the controls. Local closed-loop could still be used but only for fine adjustment of airflow which will not disturb the rest of the network.

The next consideration is dynamic vs steady-state control. In steady-state control, all controls would be adjusted all at once to provide a particular ventilation scheme. (The choice of the ventilation scheme will be discussed later). In dynamic control, the ventilation scheme would always vary based on measured contaminants underground. In such a system the actual relationship between flow and pressure cannot be approximated by a square law anymore. In order to control the system, a dynamic model is required to fix time constants based on airway length, volume, flow characteristics, air inertia, regulator characteristics, etc. This system is too complicated to model for large networks and is susceptible to the formation of unstable conditions.

To be successful, the control will have to be based on steady-state. Depending on the inertia of the system and therefore the overall number of branches of the network, the changes may be limited to every 30 minutes to 1 hour. Thus it may be better to change them twice per shift; at the start of the shift and at lunch time when miners will not be affected by the variations.

Initially, installation of an open-loop system is proposed where control element positions will be based on predetermined options for the three different shifts as well as weekend and blasting periods.

m³/s

5.1

3.4

1.7

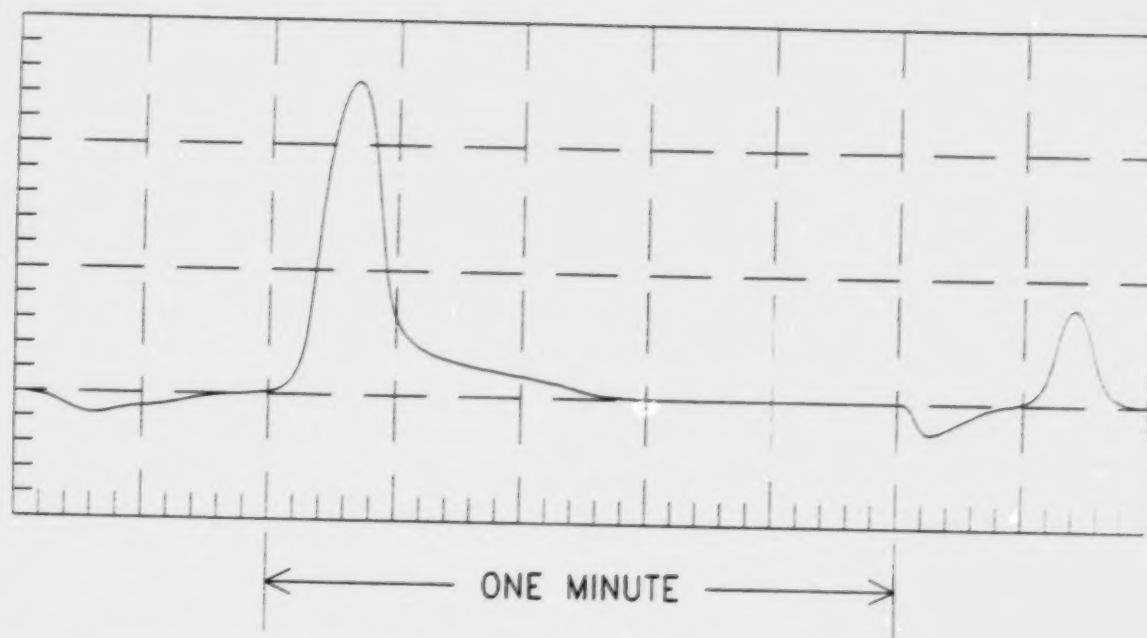


FIG. 43 RESPONSE OF REGULATOR CONTROL
UNDER SUDDEN RESISTANCE CHANGE (ref. 17)

3.4.1 Open Loop Control

The system will operate in a similar way to the Pyhasalmi mine. It will require the mine ventilation engineer to define the fresh air requirements for each level and sub-level at the beginning of each day and afternoon shifts. He will therefore have to cooperate closely with the mine supervisors in order to evaluate the diesel equipment in operation. He will then enter into the computer the various volumes required, and the position of each control element will be selected from a simple relational database in order to obtain these volumes. The positions will be transferred to another software which will control the fans and doors accordingly. During nights and weekends, the computer will control the ventilation network according to a programmed schedule. In the event of non-scheduled overtime the night or weekend captain will notify the ventilation technician on call who will in turn notify the computer via modem of the new changes. Key ventilation doors will be remotely opened prior to the blast to avoid damage to the doors. Figure 44 illustrates the interaction between the ventilation supervisor, the ventilation technician, the mine supervisors, the mine captains and the various programs of the central computer.

Once the commands have been transmitted to the control elements the computer must make certain that the volumes required on each level are reached. This will be verified by installing flow meters near the controlled fans and regulators, and transmitting their readings back to the central computer. If the volumes are not adequate, the computer will give off an alarm and provide more air to the level affected. The ventilation engineer once notified by the alarm can then check why the volume was not reached and correct the situation.

Any authorized personnel will be able to access the computer through their own personal computer (through the gandalf system) and verify the status of the entire ventilation system by viewing animated mimic graphics. All the changes made to the system as well as all data monitored underground will be archived and analyzed by the central computer. A report of this analysis will be printed on a daily and weekly basis.

If this first step is successful, the next step will be to replace the relational database with a nonlinear model based on Hardy-Cross' method. The CANMET program has already been selected by NTC and modified to provide a more user-friendly interface based on Auto-Cad.

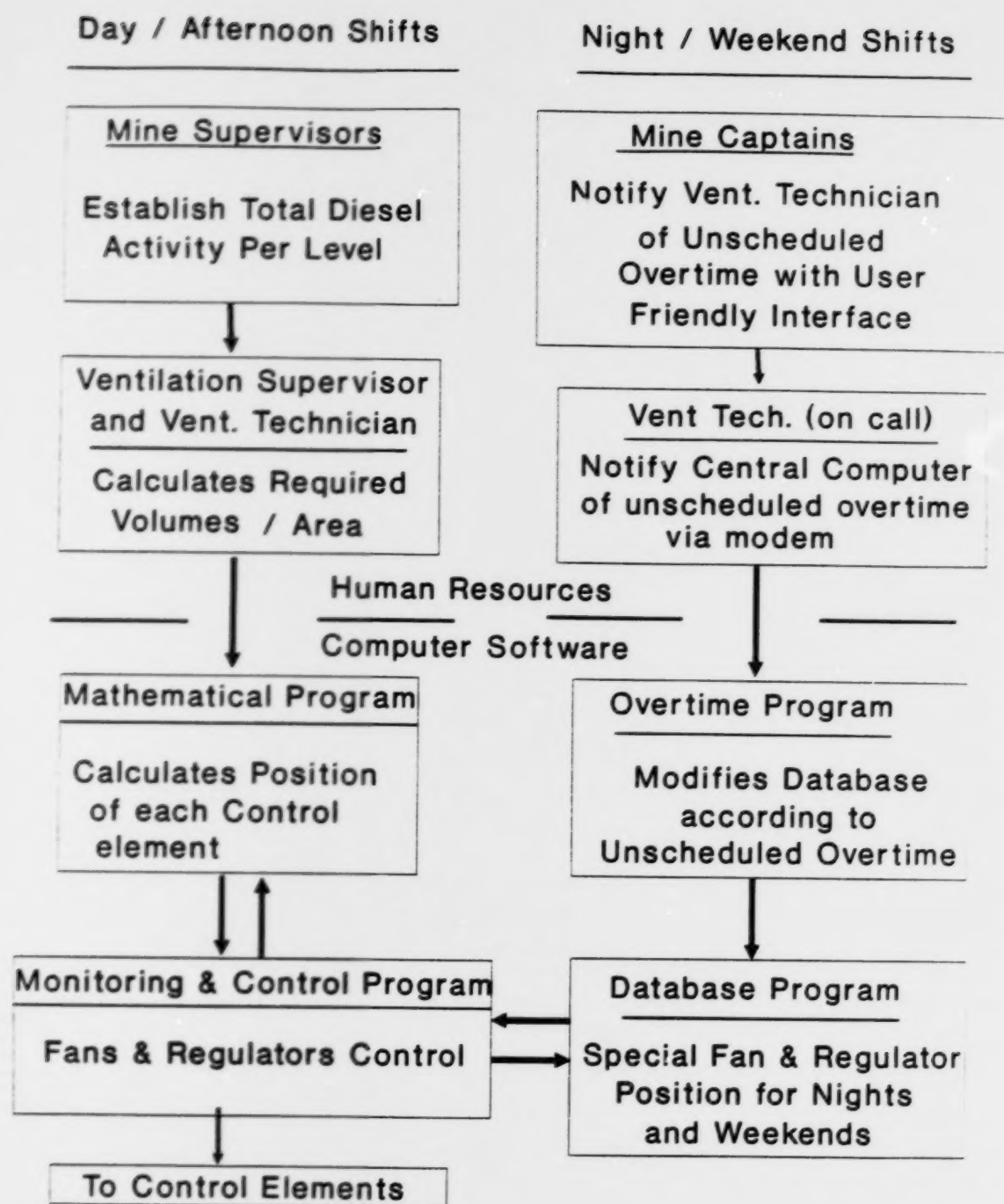


Figure 44: Central Computer / Human Interface

A preliminary model of the BMS-M network was prepared by NTC and is presented in Appendix G. The values for this network were estimated based on a preliminary pressure survey and network balance of volumes. It is essential that this model be calibrated using a more extensive pressure survey to be useful for control.

3.4.2 Closed Loop Control

Before discussing the subject of gas sensor feedback, the ventilation technique at BMS-M must be understood. Although regulators are used to control the split of air on main levels and some sublevels, natural splitting of air aided with air movers (low h.p., free-standing fans) is used to distribute the air in adjacent workings. Under such a design, it is not possible to control the workings individually, and some of the workings will always be over-ventilated (see Figure 14). This cannot be resolved with open-loop or closed-loop control. Therefore, what is the advantage of closed loop over open loop?

The first advantage of closed loop is the enhanced safety of the system. After all, the airflow is provided to control the contaminants, and a good way to measure the effectiveness of the ventilation scheme is to monitor the pollutants. The second advantage is a better distribution of airflow. With open-loop control, the system relies on the best guess of the mine supervisors as to the level of diesel activity in each working, but there are many factors which can alter this activity level. Gas feedback will permit optimization of the airflow under steady state based on actual diesel levels.

How will the closed loop be implemented?

At the beginning of this project it was expected that a pollution prediction model would be required to predict the ventilation modifications required based on the gas measurements. A pollution prediction model called M-fire, developed for fire propagation modelling at Michigan State University, was identified by NTC. After some initial trials with the model, it became quite evident that a gas monitor on every major branch in the series would be required to obtain significant results. It was concluded that it would be just as good to monitor all workings separately and calculate the modifications to the circuit required, not based on a PPM model but on a simple ratio. Therefore, if the monitor in Working A sends a value of 10 ppm and the maximum allowable value is 7 ppm, the ventilation would be increased by 30%.

The M-fire program is on a 5-1/4" diskette and the documentation has been appended (Appendix H) for reference.

3.5 Capital Investment

Table VII lists the capital investment required for the open loop control system. Table VIII describes the cost of gas monitors for closed-loop control. Note that labour costs are not included. Since the technical personnel required to install the system are already employed by BMS-M, labour is included in the current operating costs of the mine. However, it is possible that the mine will require some outside specialized labour to install the equipment within a one-year schedule in order to obtain savings rapidly.

The total savings from the control system based on a reduction of 30% in energy costs are projected to be between \$600 k and \$800 k per year.

Table VII - Open-Loop Ventilation network control

Main Surface Fans:

1.	SER drives:	V-5	225,000
		V-4	135,000
2.	Variable frequency drives:	V-2	70,000
		V-3	370,000
3.	Dupline System:	10 * FDX1400	1,870
		1 * Signal Generator	200
		1 * OLI24	400
		1 * D71910000	1,400
4.	Flow Monitor:	V-5 Electronic velocity array	25,000
		V-3 Electronic velocity array	25,000
		V-4 Electronic velocity array	15,000
		V-2 Electronic velocity array	15,000

Booster Fans and Regulators:

1.	Variable Pitch-in-motion fans:	165,460
2.	PLC system:	78 * 2032A (480 VAC) 40,755
		78 * 2051 17,710
3.	Regulators:	18 * high-press. steel door 205,632
		22 * linear actuator 17,600
4.	Single point flow monitors:	22 * 3500 77,000

TOTAL: 1,093,027

* These items may not all be required. This will only be determined after better calibration of the model.

Table VIII - Closed-Loop Upgrade

Nitric Oxide System :

1.	30 monitors (Trox system): (see Appendix --)	30,000
2.	PLC system 30*2032A	15,675
		45,675

Carbon Dioxide System :

1.	30 monitors (Gastech system) :	111,000
2.	PLC system 30*2032A	15,675
		126,675

- * For calibration, the preferred method is to purchase 5 extra units and rotate them with 5 underground units every week. The 5 removed units can be brought to the surface for calibration, using a mini-lab facility. In this way, calibration underground is avoided and all units are calibrated once every 6 weeks.

4. CONCLUSIONS AND RECOMMENDATIONS

In Phase II, it has been explained in detail how both open and closed loop can be achieved. The control of the ventilation system is no different in a closed-loop or open-loop system. The only difference is that, in an open-loop system, the set-points are adjusted by human interface, and in a closed-loop the set-points are adjusted through sensors feedback.

The critical factor of any control system is whether the changes are made under steady or dynamic state. For ventilation automation, steady-state was favoured. A successful example of such a system, presented in Phase II, is the Pyhasalmi experience.

Conventional control is based on PID error correction, but this was shown to be inappropriate for ventilation network control. The control logic must be based around a relational database or a well-calibrated computer model.

Based on the work carried out under this contract, it is recommended that, first, an open-loop control system be developed at Brunswick. For testing all control elements and central logic, the system should first be implemented on a single main level. This has been proposed to BMS-M for 1989/90.

Closed-loop control is not feasible by itself since the contaminants cannot be represented properly by one gas and the control will be achieved under steady-state (closed-loop was developed for dynamic control).

There is still some considerable advantages to gas monitoring in ventilation automation. NTC recommends the use of a combination of closed and open loop for automation. In such a system, the ventilation would be set by the ventilation engineer at the beginning of each shift (based on forecast requirements). Sensors placed at critical areas of the mine would then send back information on contaminant concentrations in the areas monitored. These levels would be compared with acceptable levels and the ventilation of under-ventilated areas would be quickly adjusted to proper levels. Over-ventilated areas would not be re-adjusted.

Since no single gas can be used alone, and it is not feasible to monitor all gases, it is best to select two or three contaminants to provide feedback information. RCD should be one of the pollutants monitored since its ratio compared to its TLV is the highest at BMS-M (and in most dieselized mines). However, there are no adequate sensors available at present.

The monitoring of both NO and CO₂ would be an excellent combination. NO is present in the mine at concentrations closest to its TLV. It is not affected by the propane burners and it is generated in large quantities during a blast. The sensors are reliable and sufficiently accurate. CO₂ is present in very high concentrations underground and small changes in contaminant levels produce large changes in the CO₂ level. This, combined with the fact that the IR sensors manufactured have a quick response, makes CO₂ an ideal to identify anomalies in the ventilation circuit. Also, the CO₂ sensors can be used for fire monitoring underground.

More research is required into open-loop and semi-closed loop ventilation control. The research carried out under this contract has provided a solid base for ventilation automation. The next step now is to implement a completely automated pilot system in a mine. Both government, mine management and workers stand to benefit from this work since it will provide a safe work environment and reduce energy consumption substantially.

REFERENCES

1. Aldridge, M.D. (July 1980). Automation of mine ventilation systems: Progress and prospects. Society of Mining Engineers of AIME, Vol. 266.
2. Obert, E.R. (1950). Internal combustion engines. International Textbook Co., Scranton, PA, 2nd Ed., 596 p.
3. Stewart, D.B., Mogan, P., and Dainty, E.D. (1978). Diesel emissions and mine ventilation. CIM Bulletin, Vol. 71, No. 791, p. 144-151.
4. Holtz, J.C., and Dalzell, R.W. Diesel exhaust contamination of tunnel air. U.S. Bureau of Mines RI 7074, 1968, p. 23.
5. Hurn, R.W. Diesel emissions measurement and control. Proceedings of the Symposium on the Use of Diesel-Powered Equipment in Underground Mining, Pittsburgh, Pa, January 1973.
6. Johnson, J.H. (1980). Overview of monitoring and control methods for diesel pollutants in underground mines using diesel equipment. CIM Bulletin, Vol. 73, No. 819, p. 73-87.
7. Daniel, J.H. Diesels in underground mining: A review and an evaluation of an air quality monitoring methodology. U.S. Bureau of Mines Report of Investigation, No. 8884, 1984.
8. French, I.W., and Mildon, C.A. Health implications of exposure of underground mine workers to diesel exhaust emissions - An update. CANMET contract No. 0SQ82-00121, 1984.
9. Johnson, J.H., et al. The development and application of advanced mine air monitoring techniques to mines using diesel powered equipment. Final report for NTIS-Mining Enforcement and Safety Administration (MESA), PB 258 038, February 1979.

10. Johnson, J.H., et al. Monitoring of mine air diesel pollutants tailpipe emissions measurement apparatus, detector tube interferences, and exhaust and ventilation system control. Report prepared for U.S. Bureau of Mines, NTIS PB 82-148388, July 1980.
11. Gangal, M.K., et al, Evaluation of diesel emissions control technology at Noranda's Brunswick Mining and Smelting Mining Division. Seventh Annual Technical Session of the CIM, Bathurst, New Brunswick, 5 September 1986.
12. Trutwin, W., A numerical simulation of transient states of the ventilation process and the control of the mining ventilation networks. Zeszyty Problemoew Gornictwa Pan, Vol. 10, No. 2, Krakow, Poland (1964).
13. Aldridge, M.D., Automation of mine ventilation systems : Progress and Prospects. Society of Mining Eng. of AIME, Transactions Vol. 266 (1986).
14. Seppanen, P., et al, Computer-controlled mine ventilation system at the Pyhasalmi Mine, Finland, Computer methods for the 80's in the mineral industry. A. Weiss, ed. 1979, Baltimore, Maryland, Port City Press.
15. Ching, C.B., Automatic control of the mine ventilation system at Hsikwangshan. Proceedings of the third mine ventilation symposium, Penn State U., University Park, Pennsylvania, 12 - 14 October 1987.
16. Patigny, J., Application of process control to mine ventilation. IXth World Mining Congress, Federal Republic of Germany, May 1976.
17. Street and Wylie, Fluid Mechanics, First SI metric edition, McGraw-Hill Ryerson Ltd., 1981.
18. Mahdi, A.A., and McPherson, M.J., An introduction to automatic control of mine ventilation systems, Mining Technology Journal, pp. 5-10, May 1971.

APPENDIX A

CO₂ AND CONTAMINANTS CORRELATIONS

A-1 : NO vs CO₂

A-2 : CO vs CO₂

A-3 : NO₂ vs CO₂

A-4 : SO₂ vs CO₂

DATA ORGANIZATION

Throughout this appendix, several different types of data are presented. A summary of these types appears below:

A) Exh. Correlation

The correlation between the individual contaminant and CO₂ without any correction for background.

B) Avg. Exh. Correlation

Same as A) except 15 min. averages are used.

C) Corr. Exh. Correlation

The correlation between the individual contaminant and CO₂ corrected for background.

D) Corr. Avg. Exh. Correlation

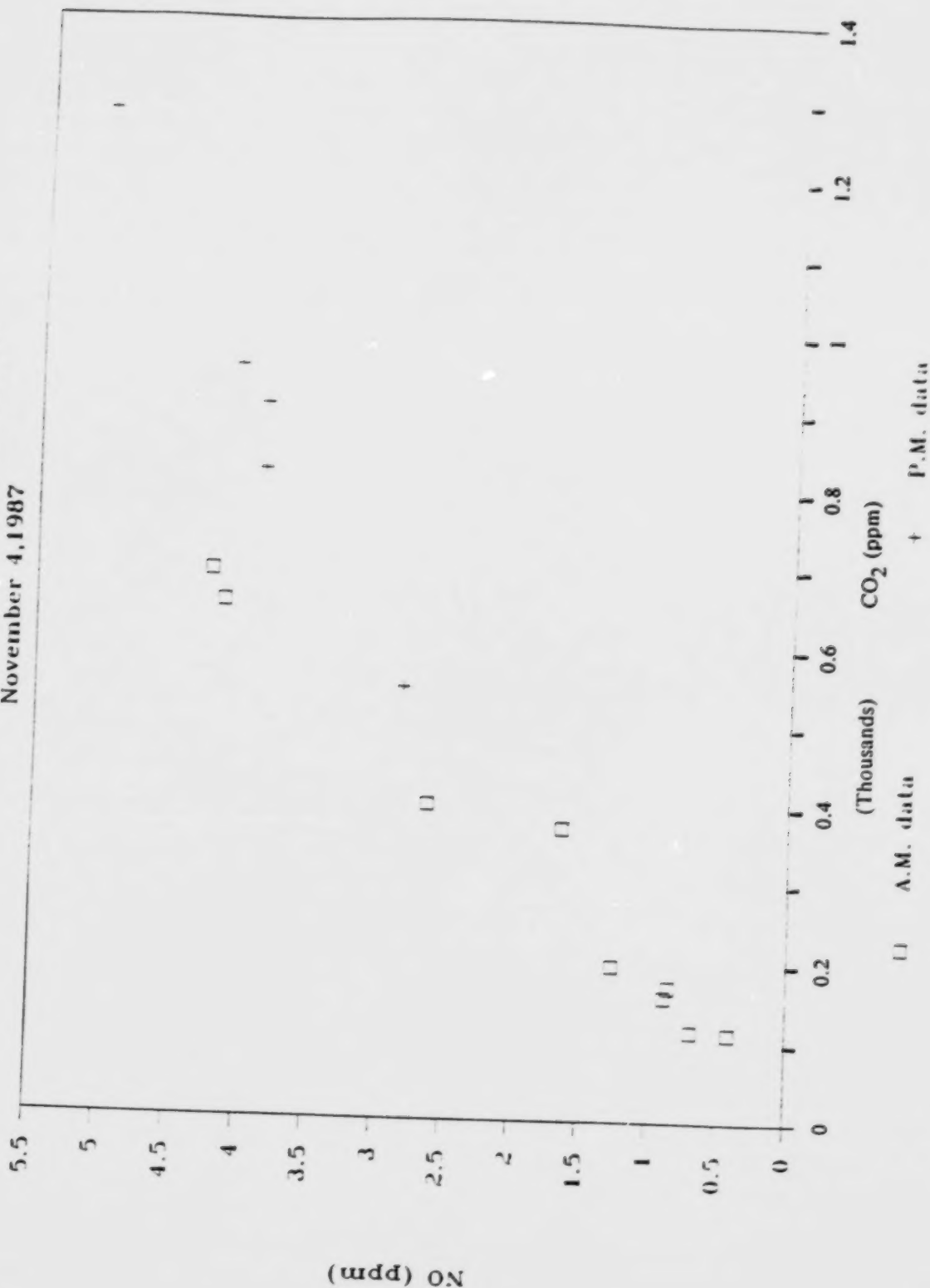
Same as C) except 15 min. averages are used.

APPENDIX A-1

NO vs CO₂

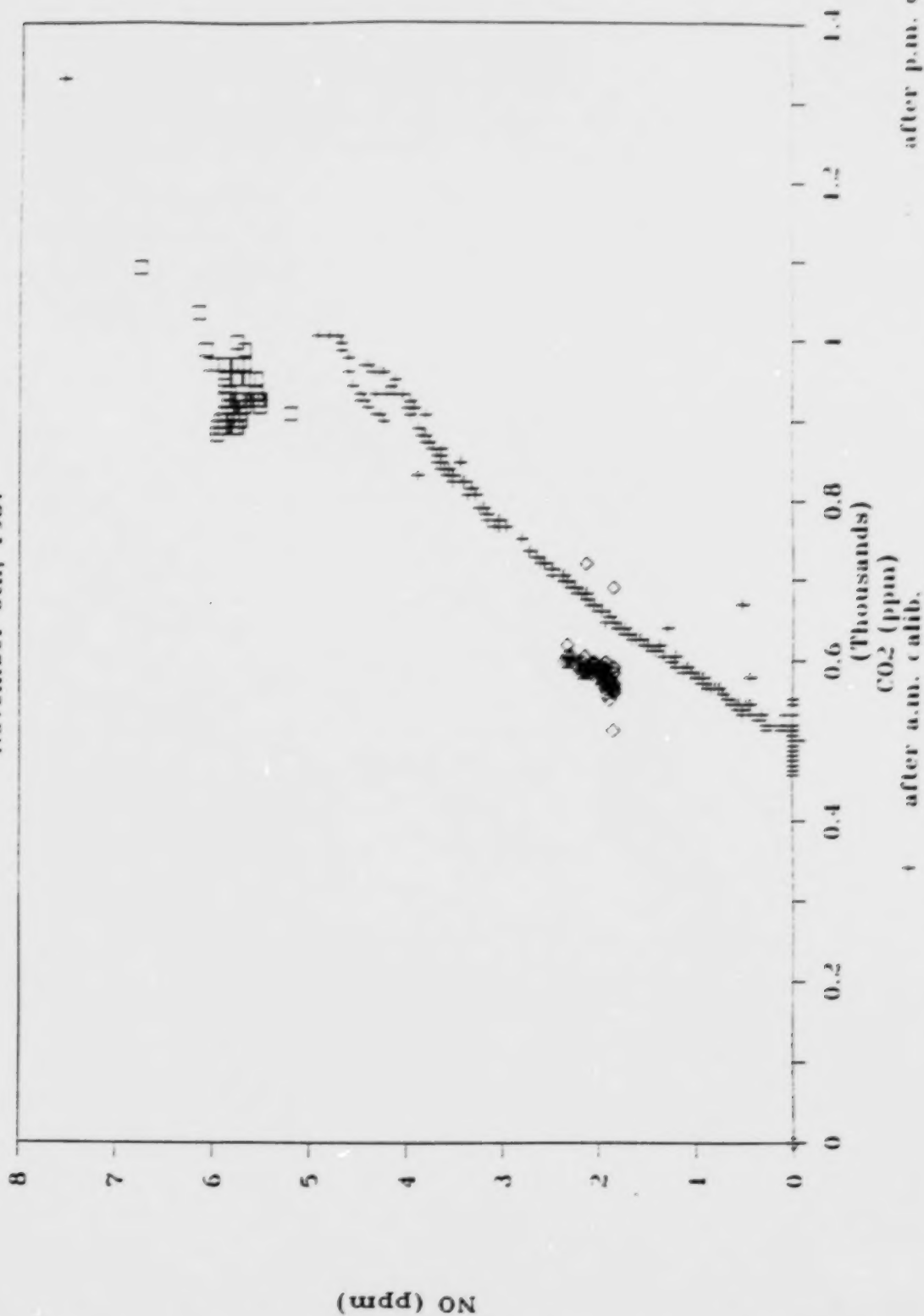
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



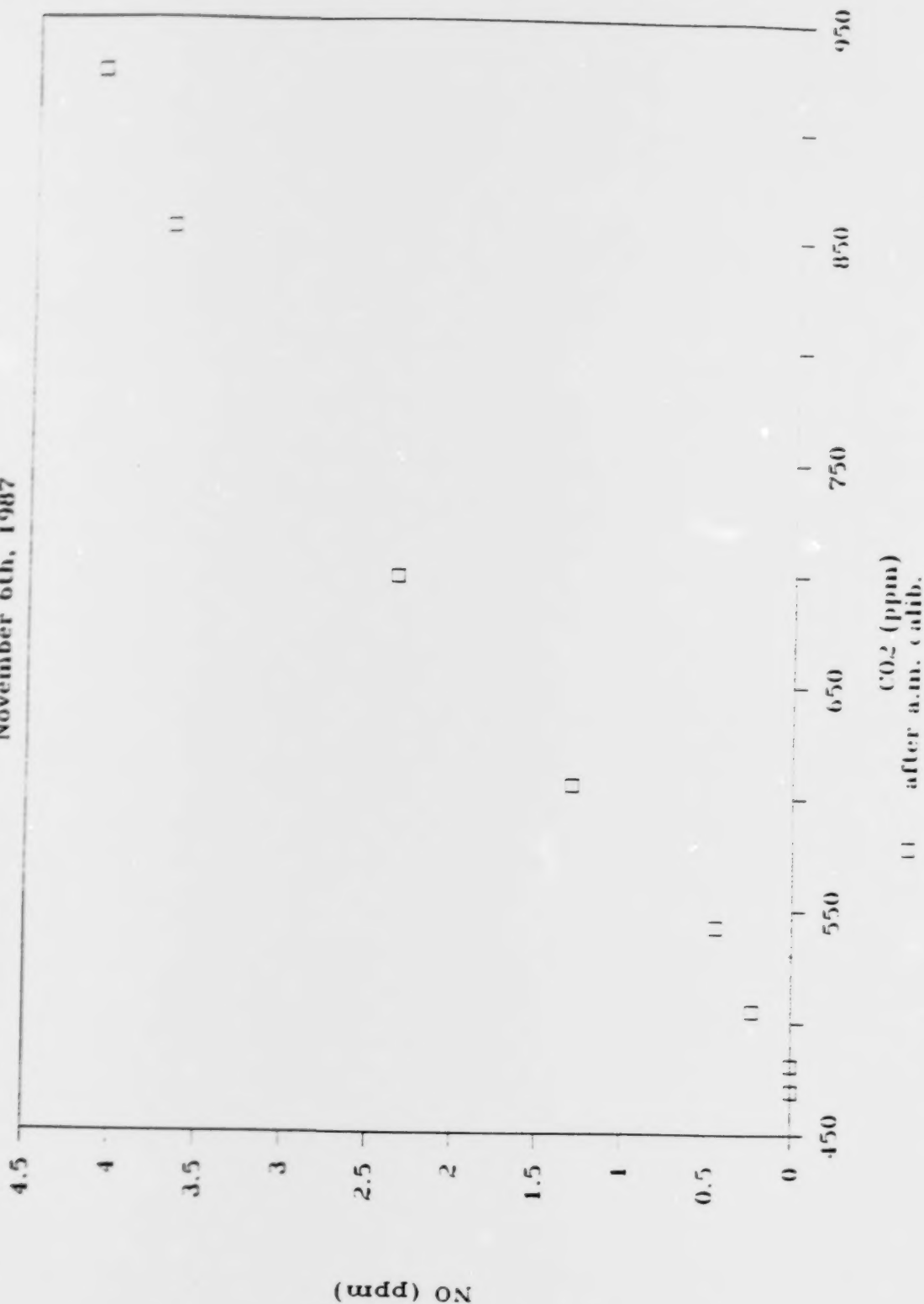
1000 LEVEL EXH. CORRELATION

November 6th, 1987



1000 LEVEL AVG. EXH. CORRELATION

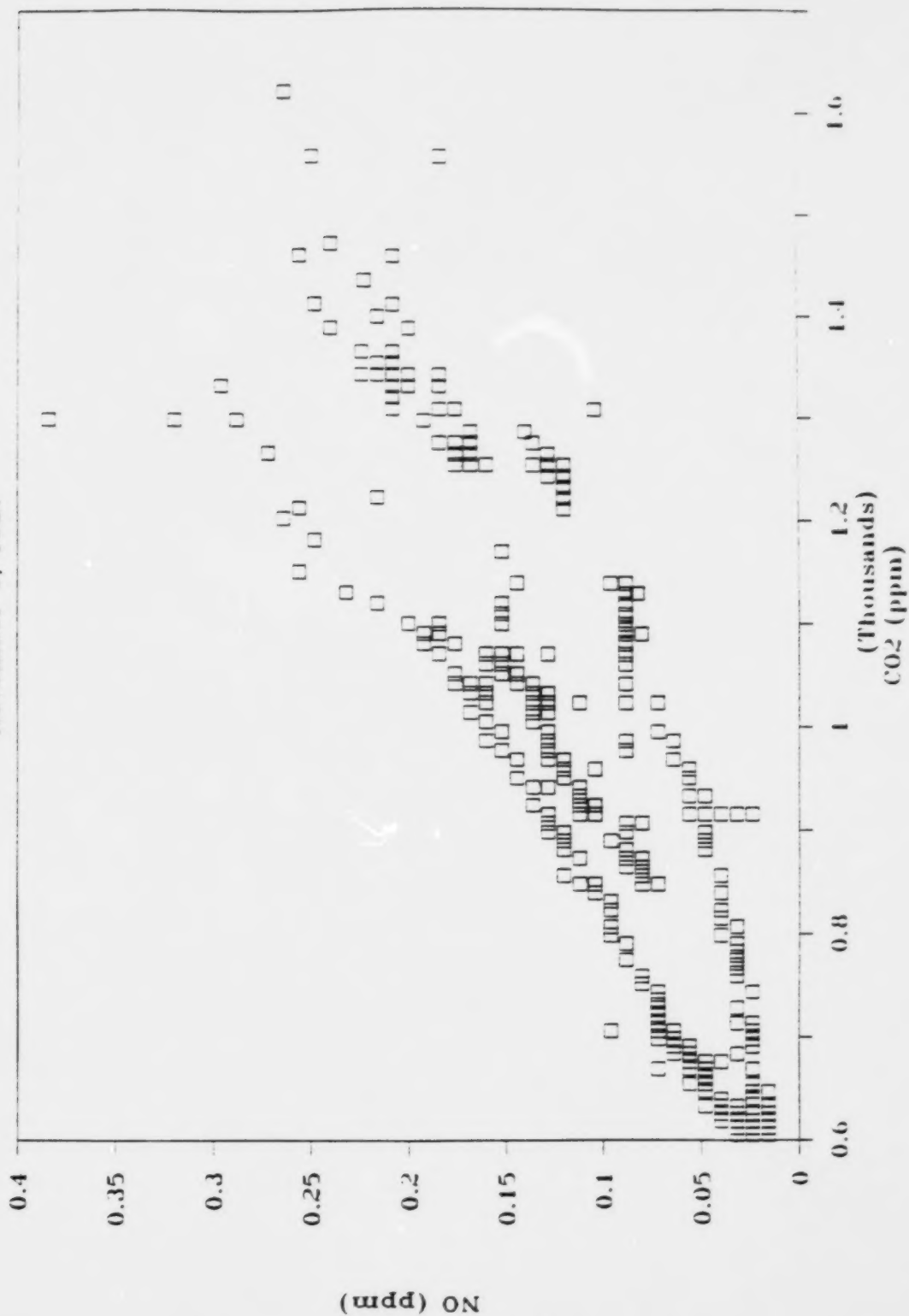
November 6th, 1987



A-1-3

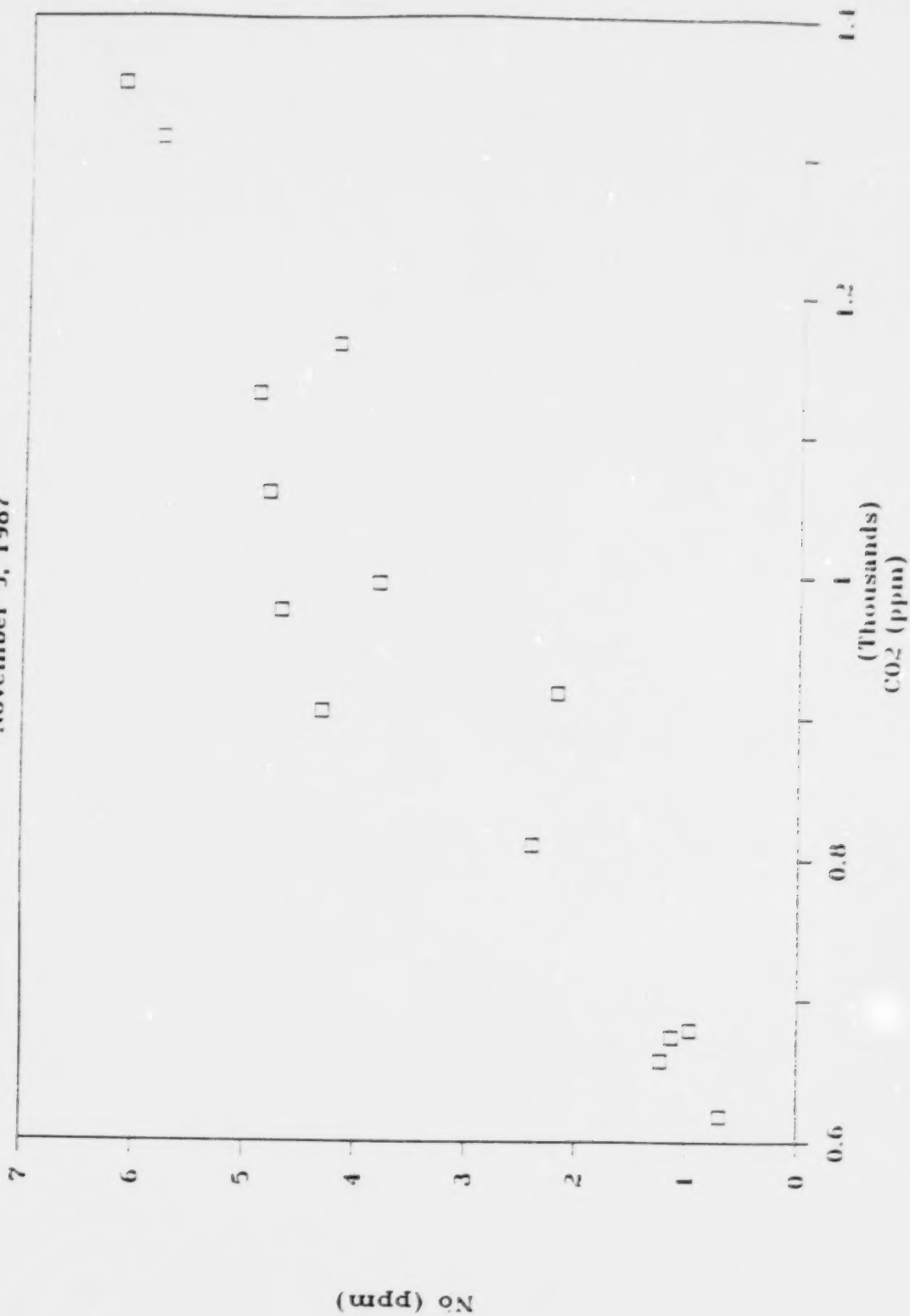
1000 LEVEL EXH. CORRELATION

November 5, 1987



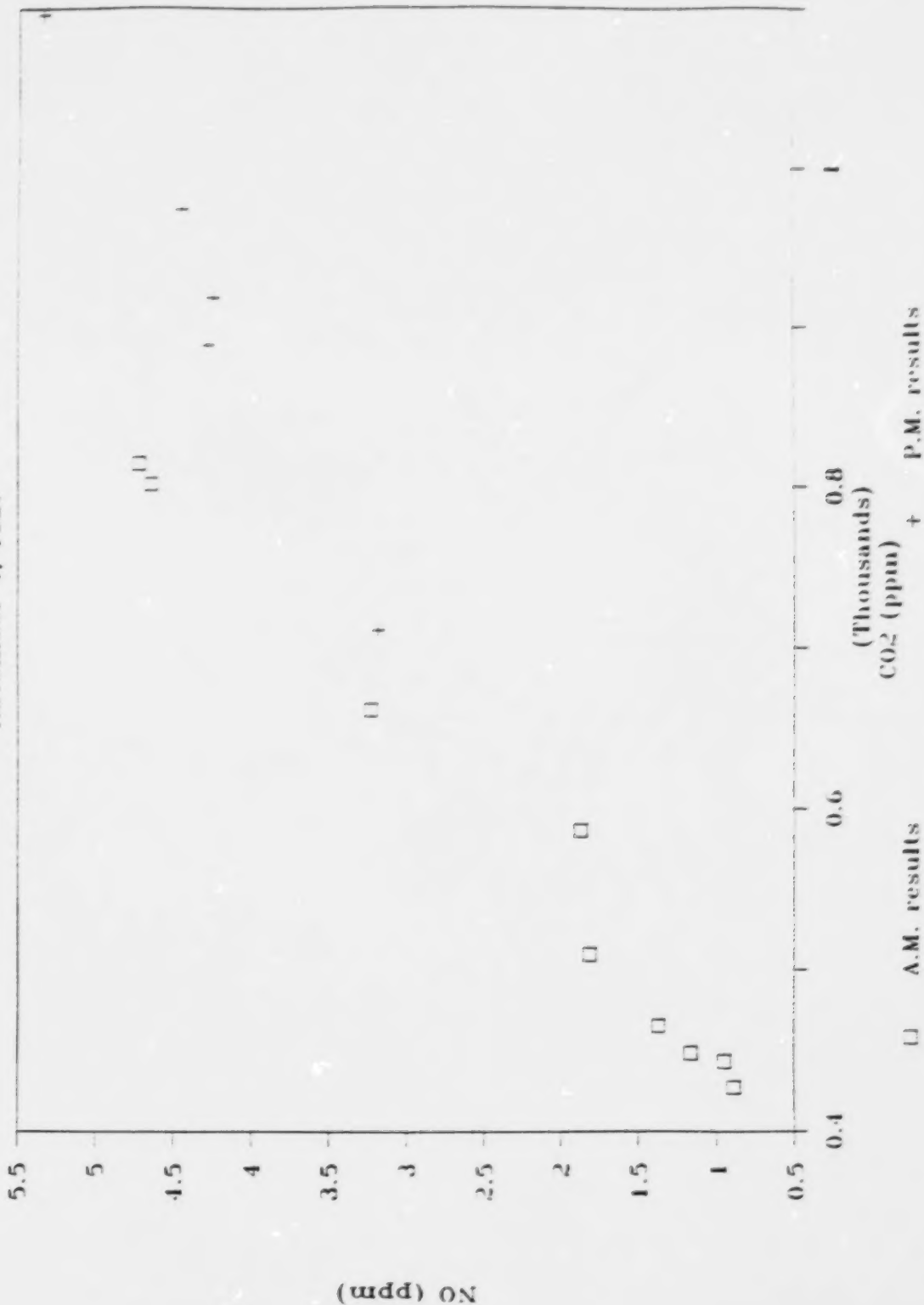
1000 LEVEL AVG. EXH. CORRELATION

November 5, 1987



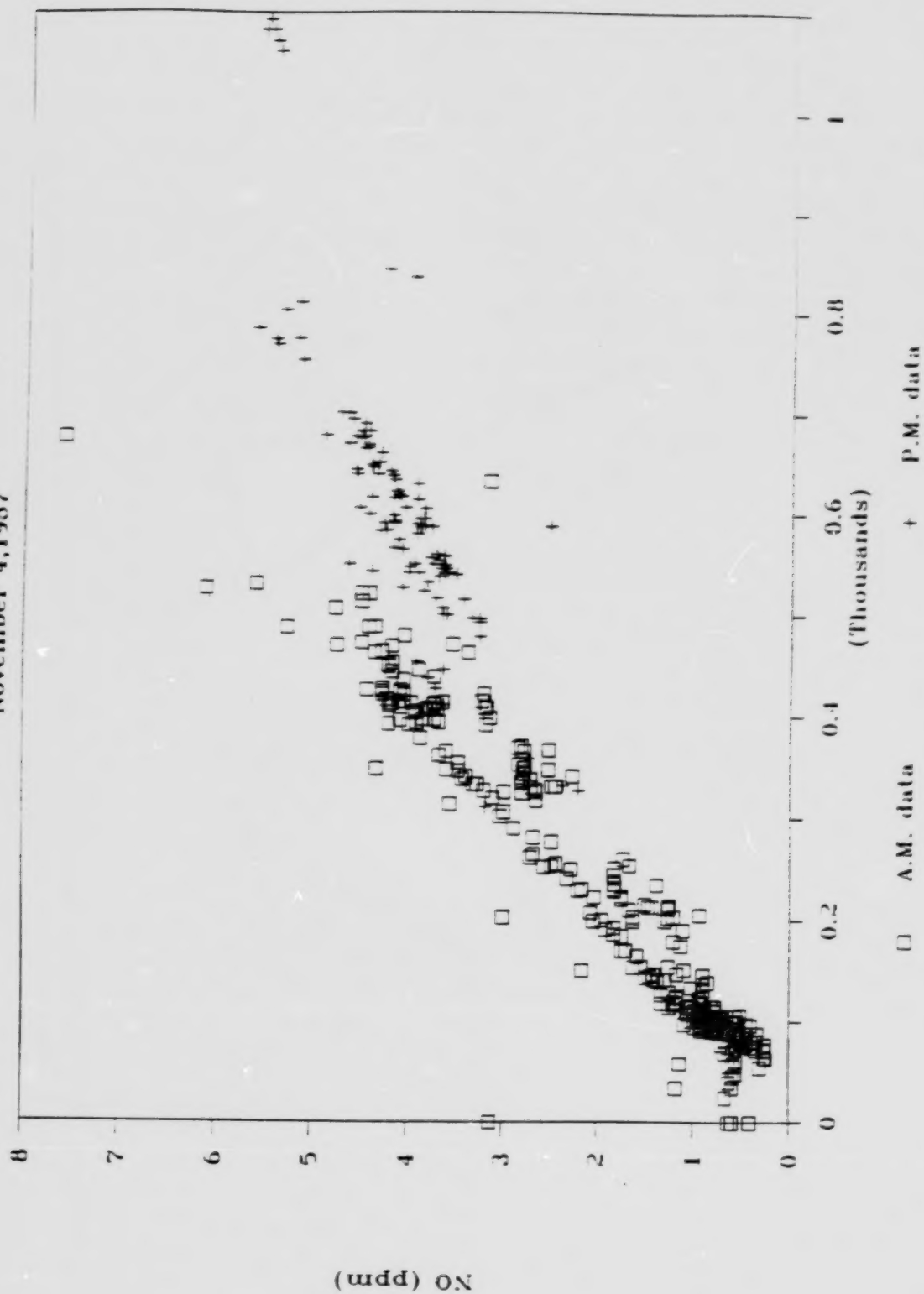
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



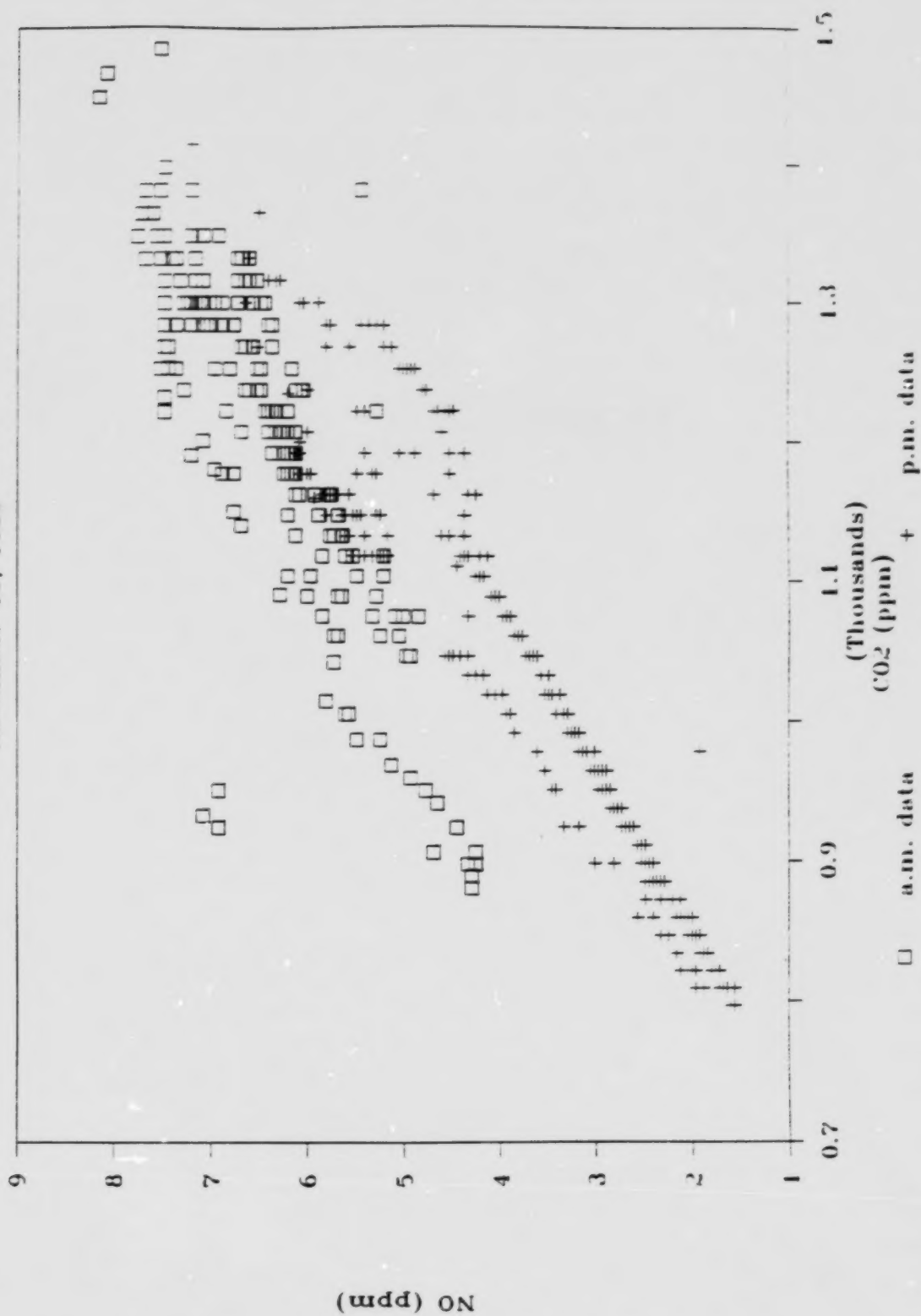
1000 LEVEL EXH. CORRELATION

November 4, 1937



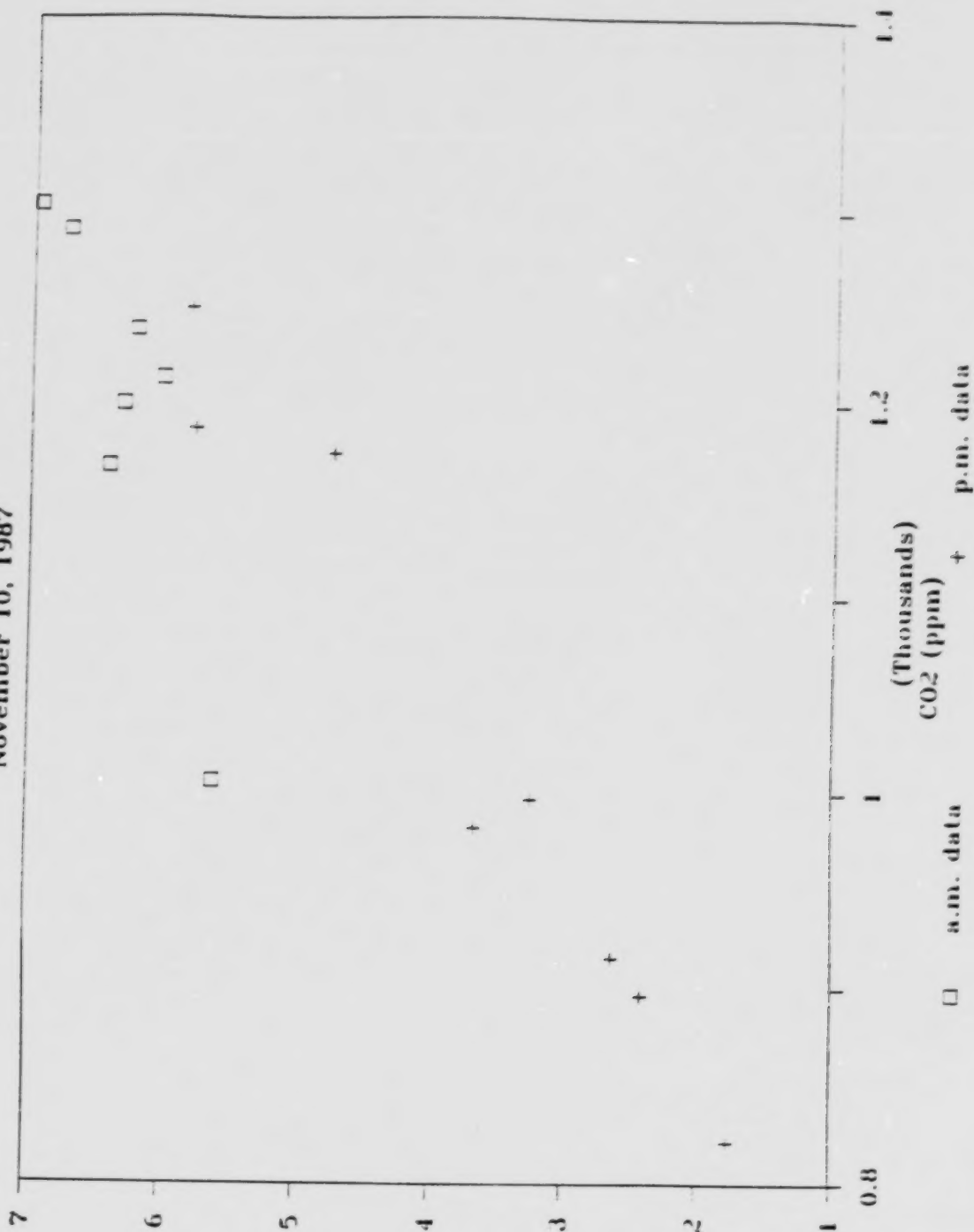
725 LEVEL EXH. CORRELATION

November 10, 1987



725 LEVEL AVG. EXH. CORRELATION

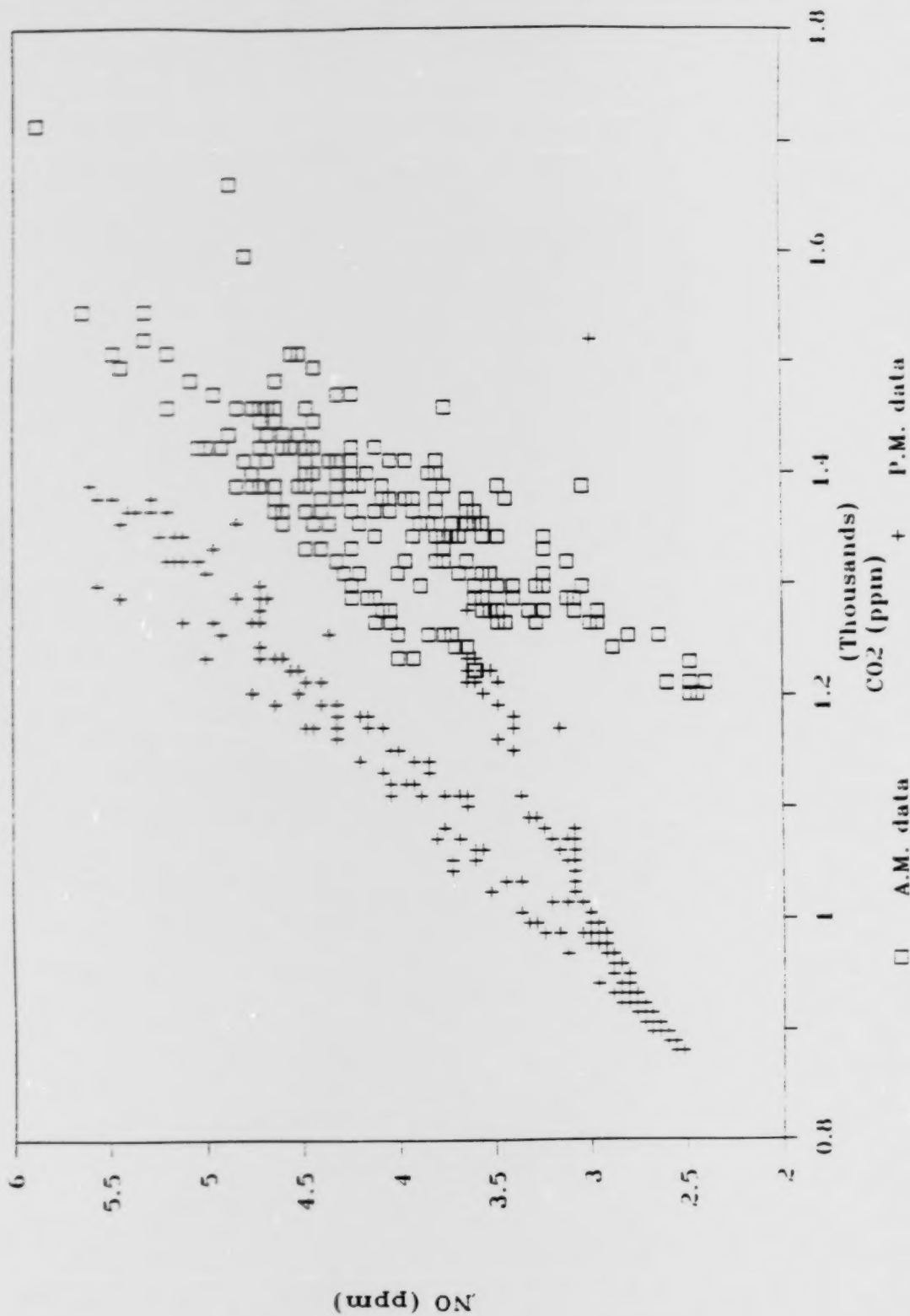
November 10, 1987



(wdd) ON

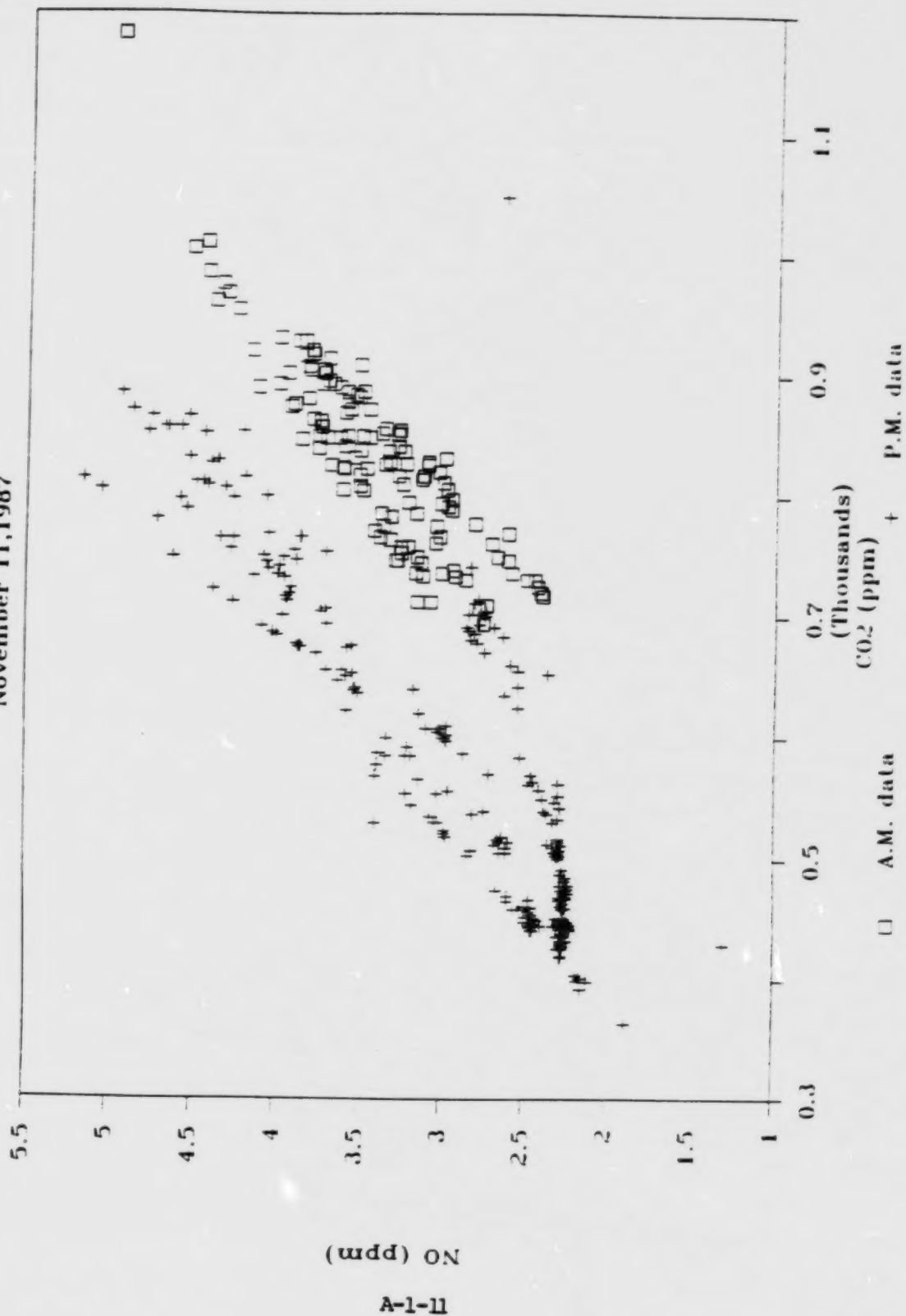
725 LEVEL EXH. CORRELATION

November 11, 1987



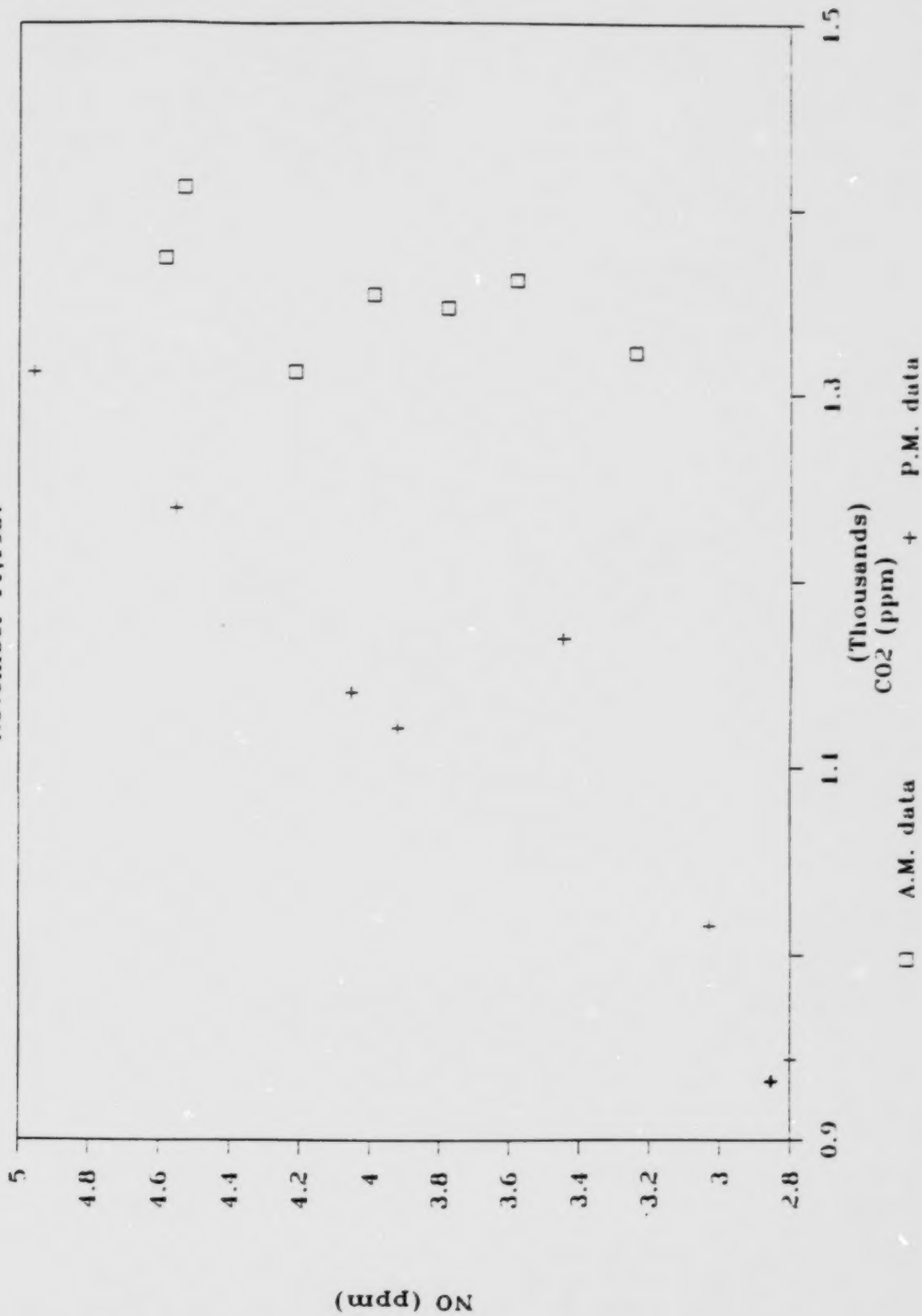
725 LEVEL CORR. EXH. CORRELATION

November 11, 1987



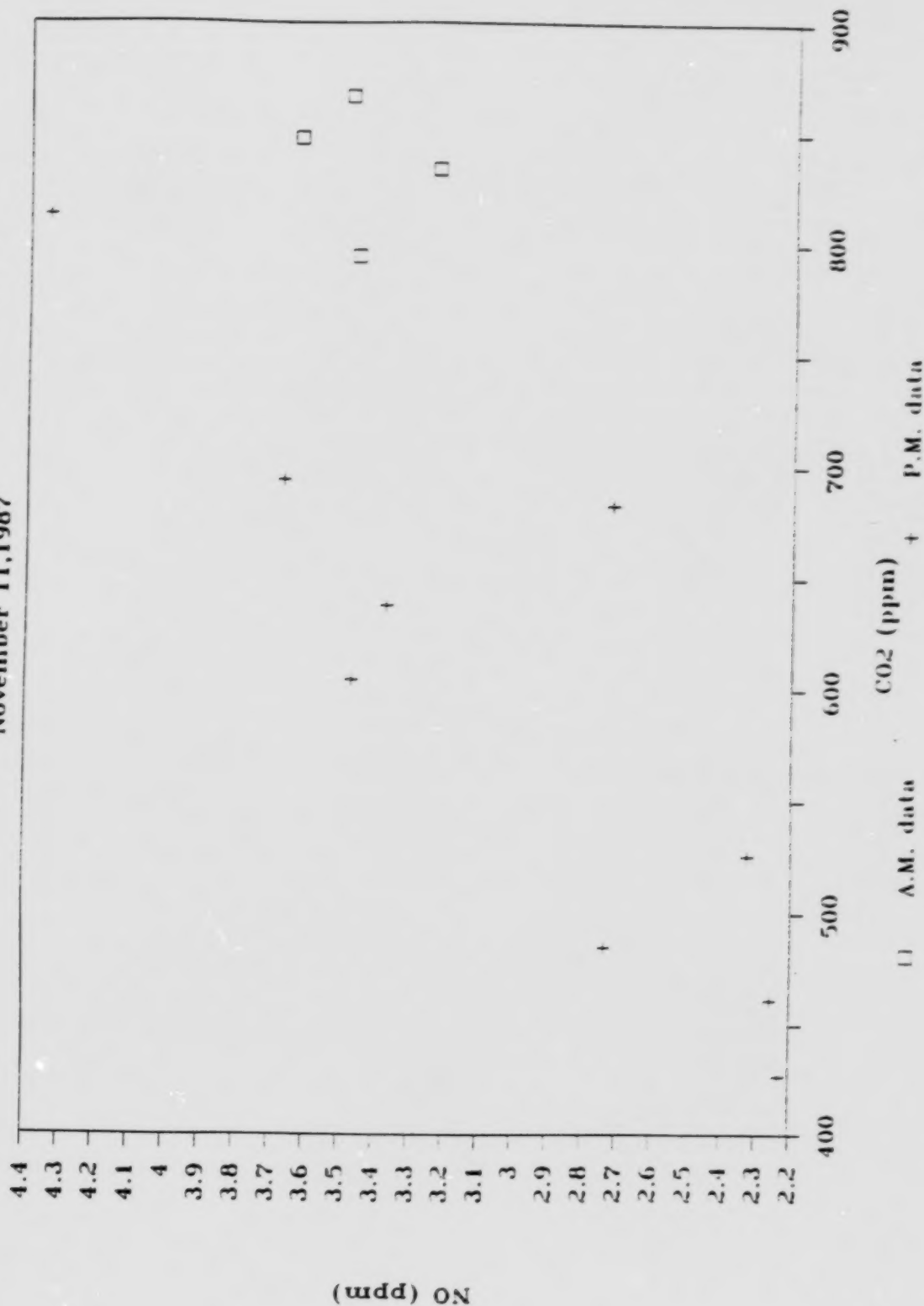
725 LEVEL AVG. EXH. CORRELATION

November 11, 1987



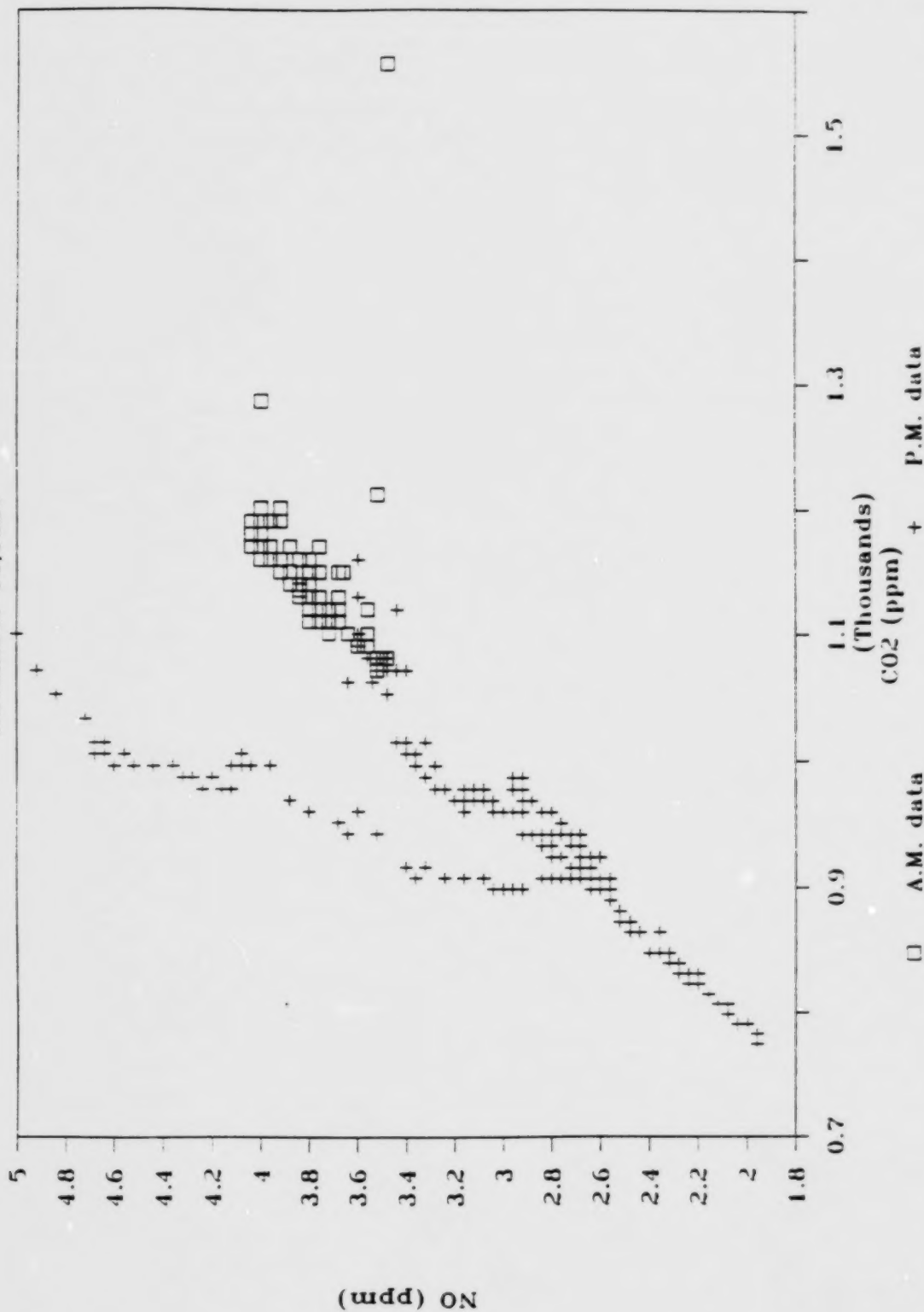
725 LEVEL CORR. AVG. EXH. CORRELATION

November 11, 1987



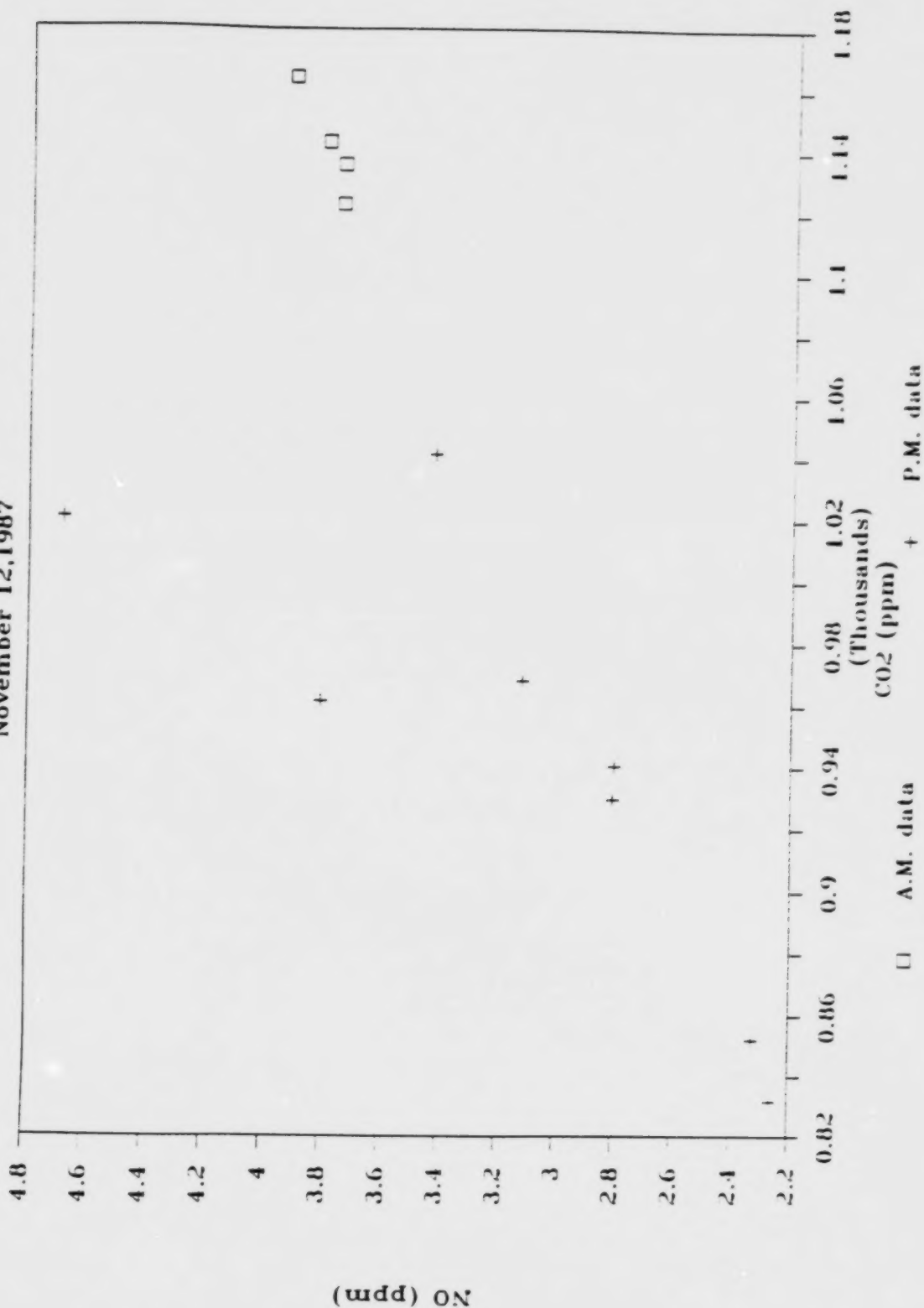
725 LEVEL EXH. CORRELATION

November 12, 1987



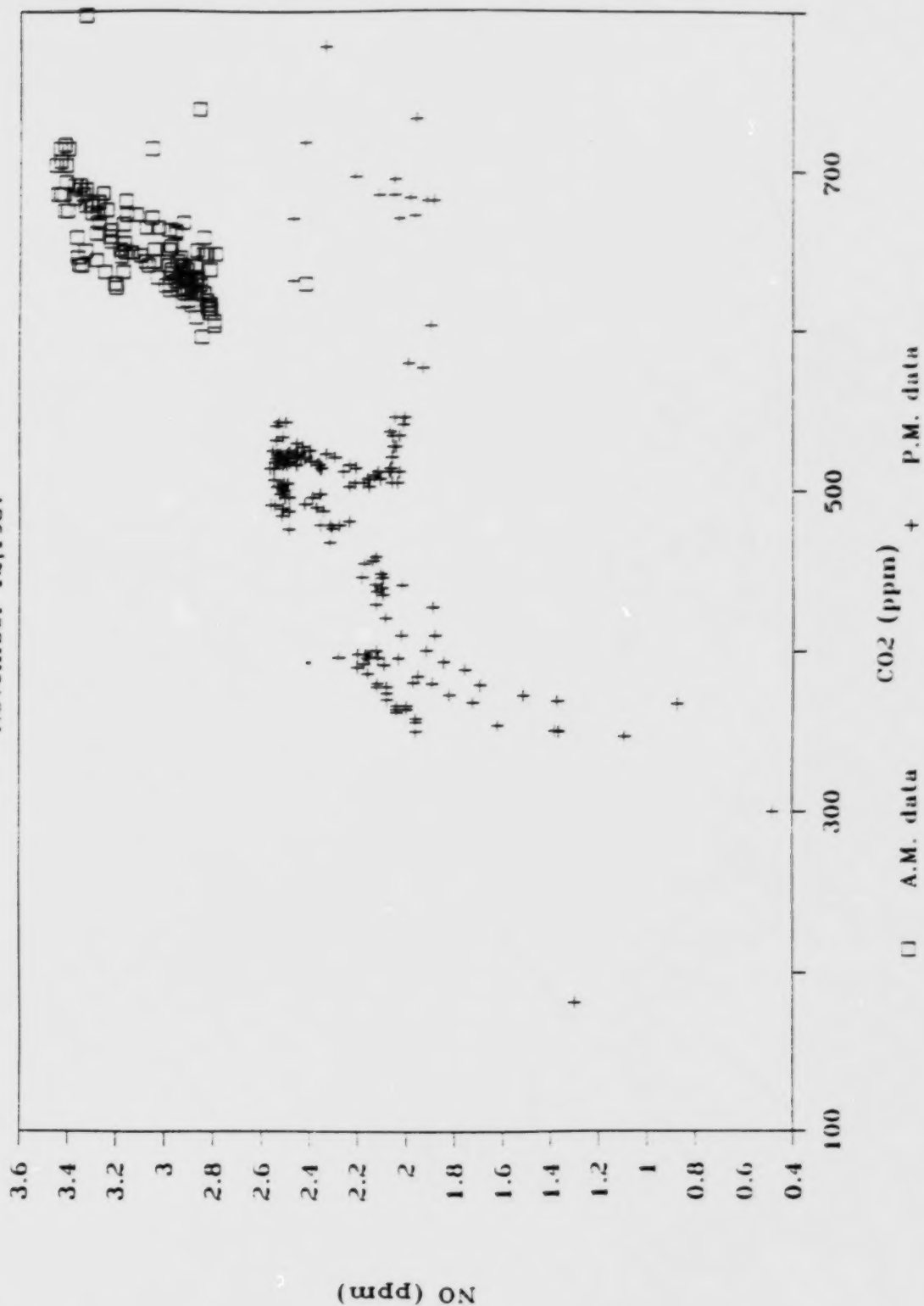
725 LEVEL AVG. EXH. CORRELATION

November 12, 1987



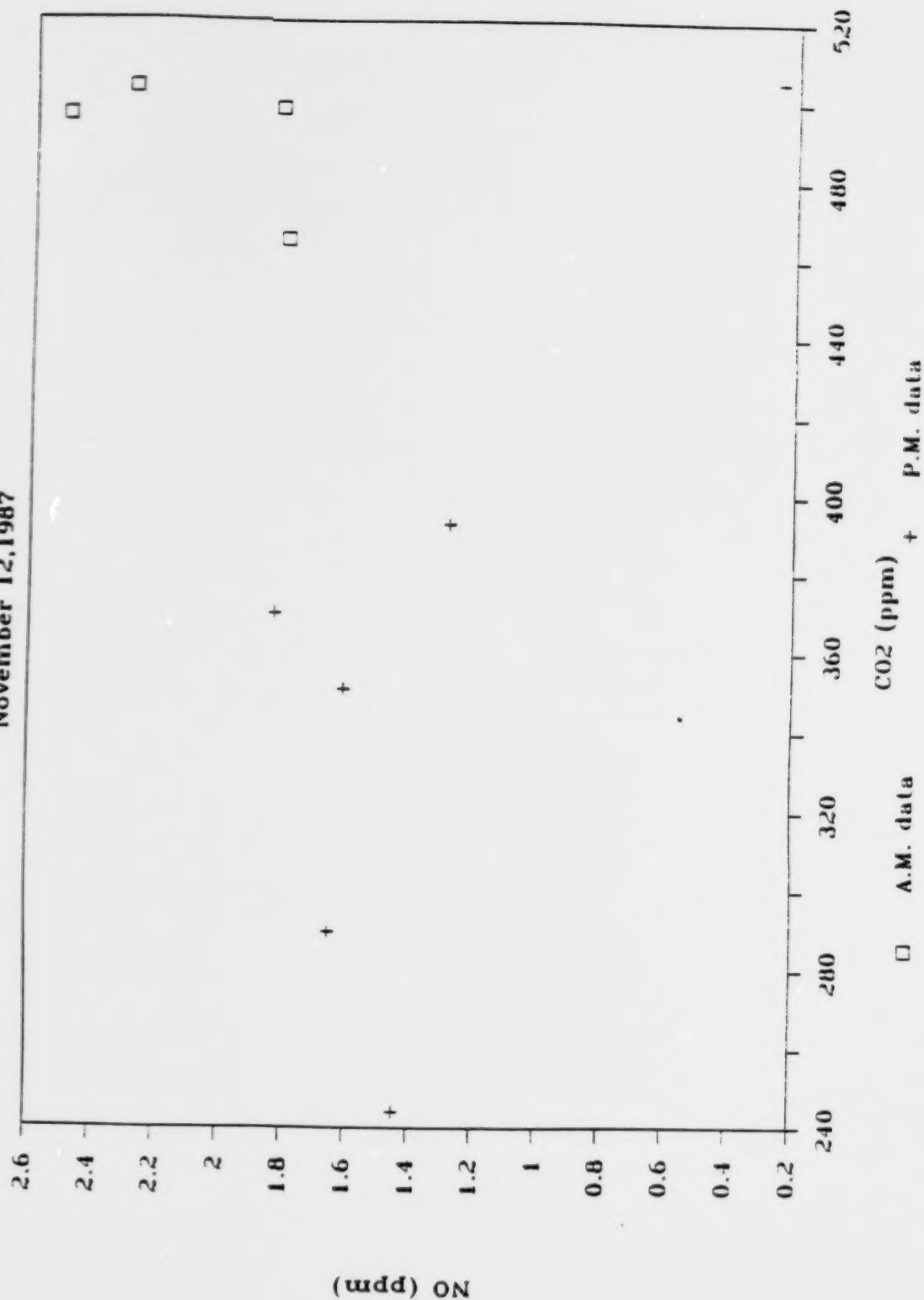
725 LEVEL CORR. EXH. CORRELATION

November 12, 1987



725 LEVEL CORR. AVG. EXH. CORRELATION

November 12, 1987

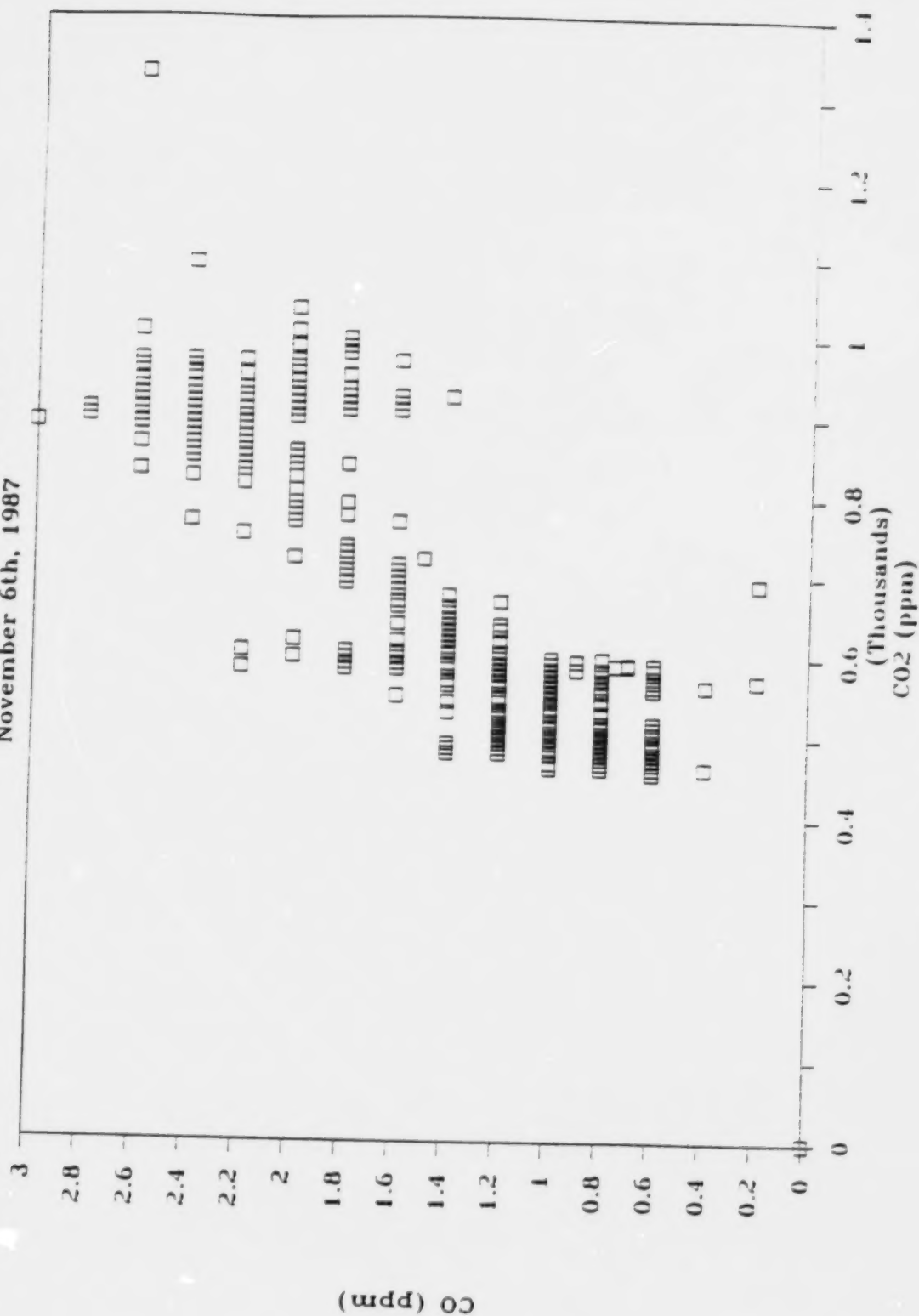


APPENDIX A-2

CO vs CO₂

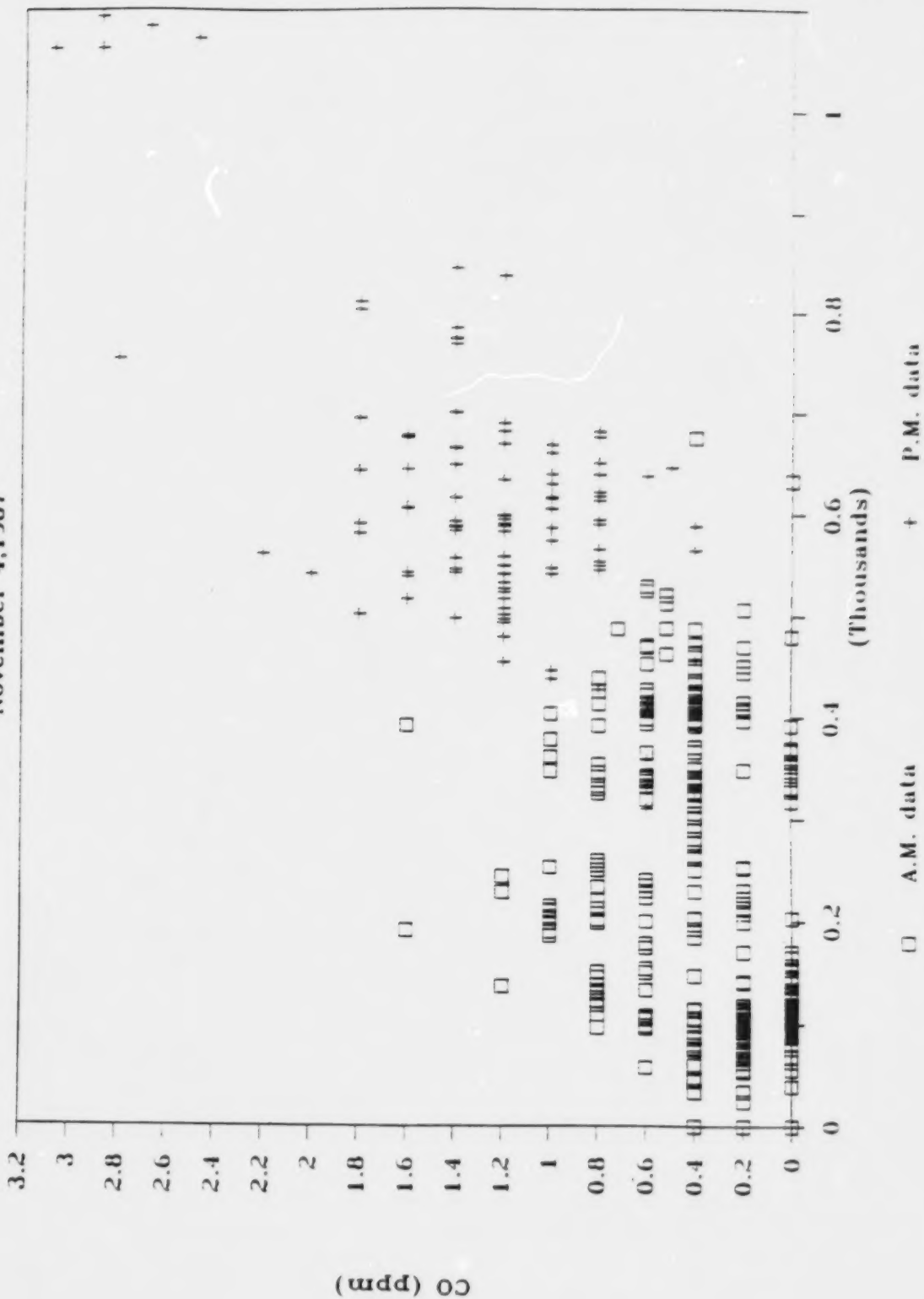
1000 LEVEL EXH. CORRELATION

November 6th, 1987



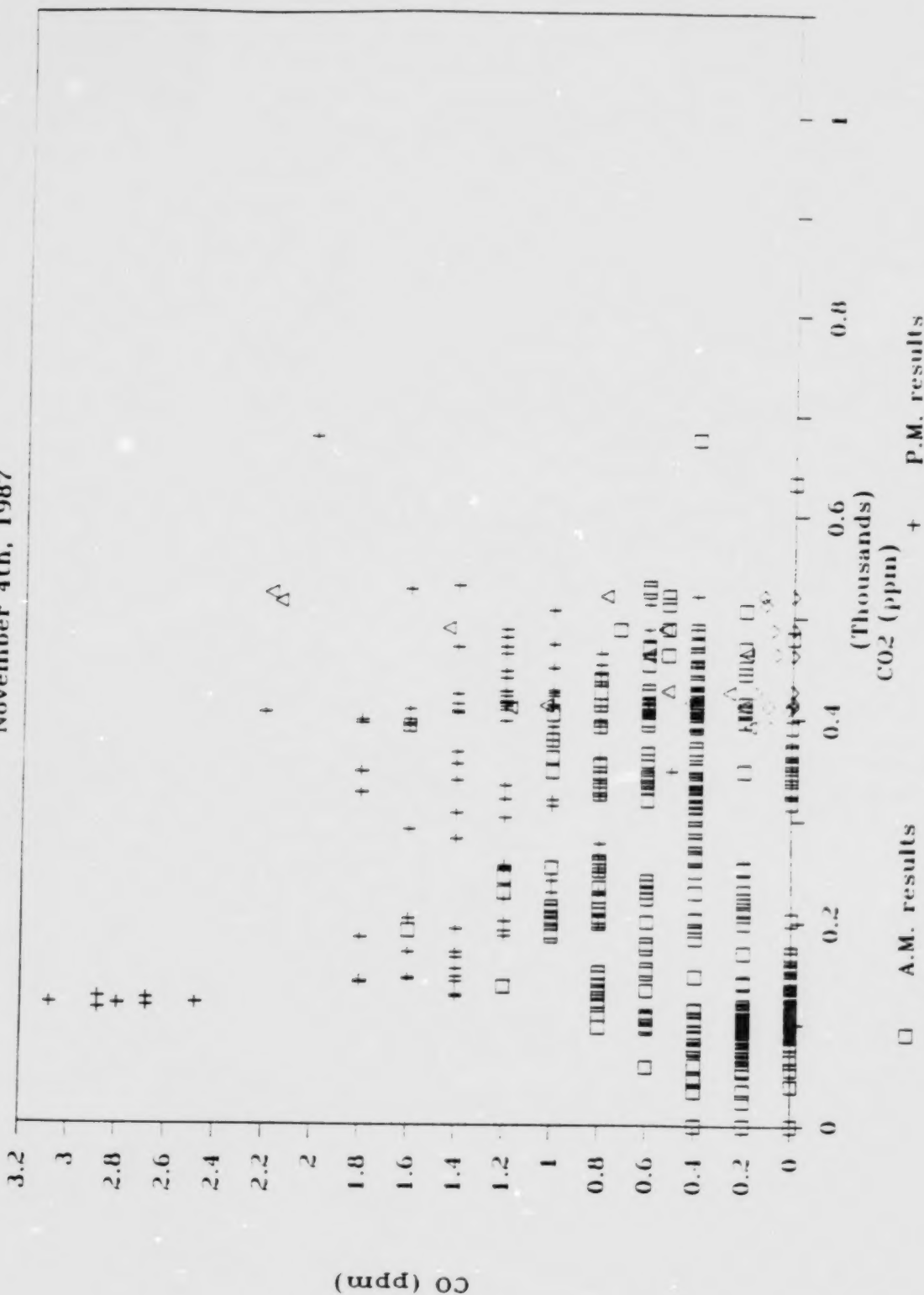
1000 LEVEL EXH. CORRELATION

November 4, 1987



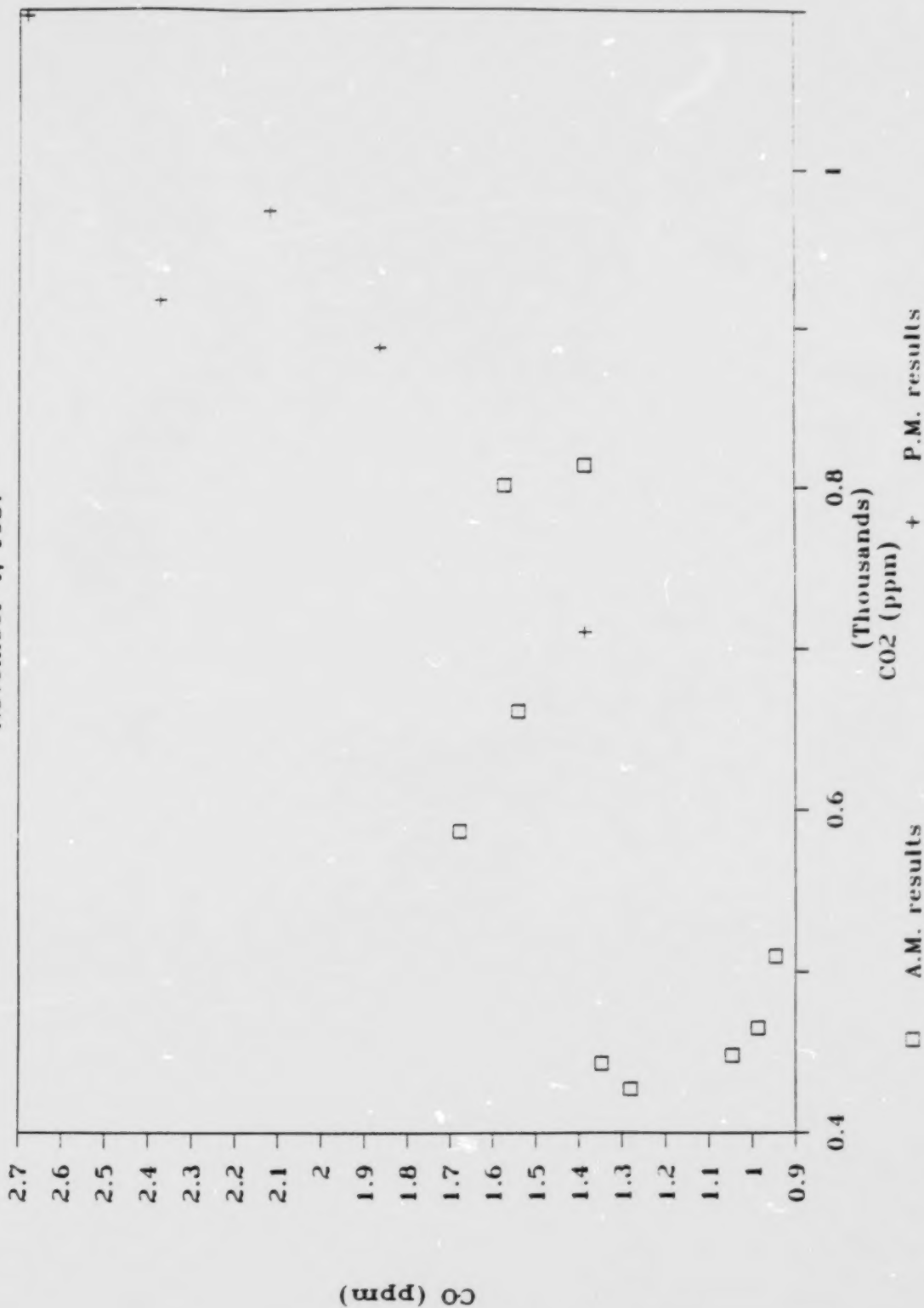
1000 LEVEL CORR. EXH. CORRELATION

November 4th, 1987



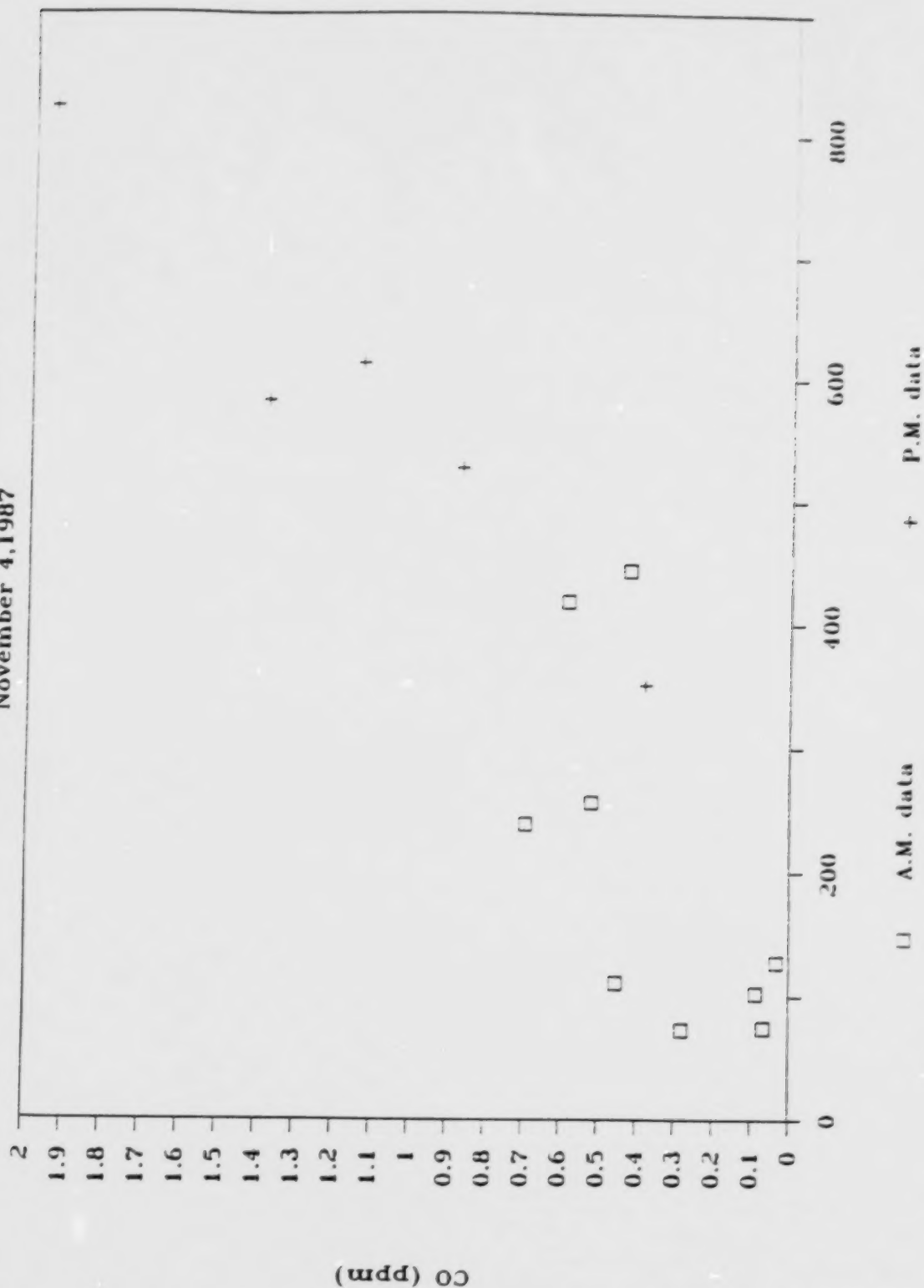
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



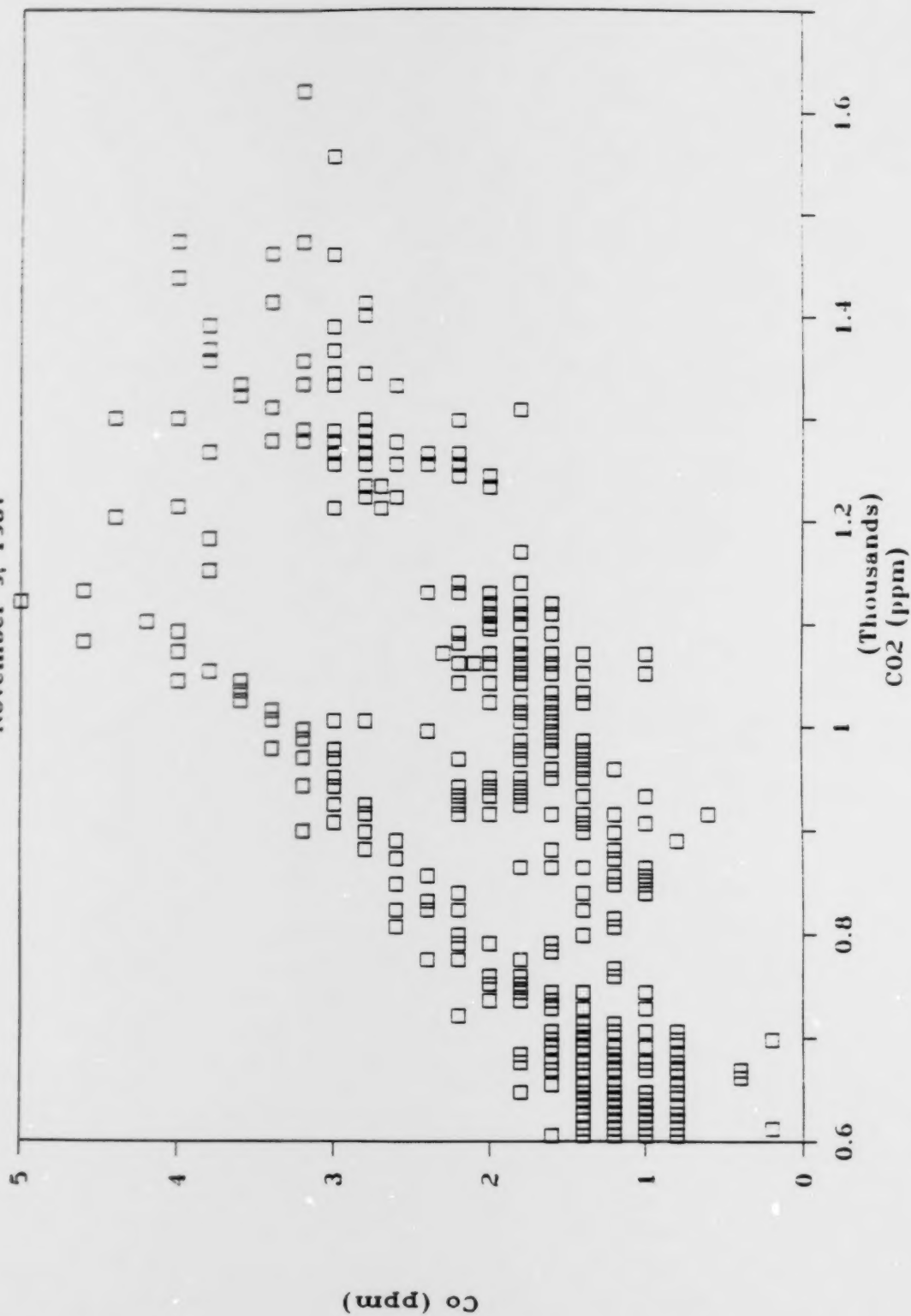
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



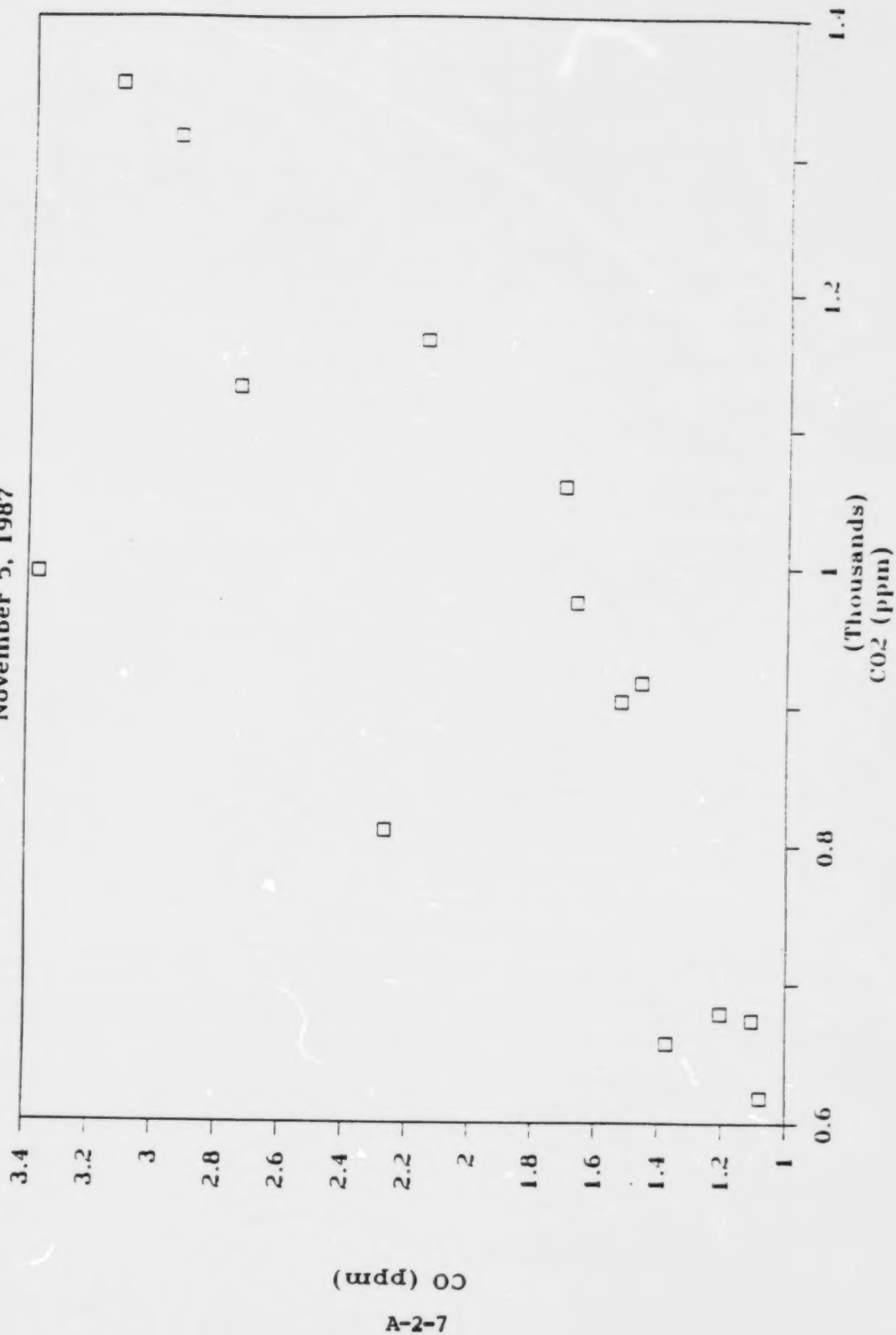
1000 LEVEL EXH. CORRELATION

November 5, 1987



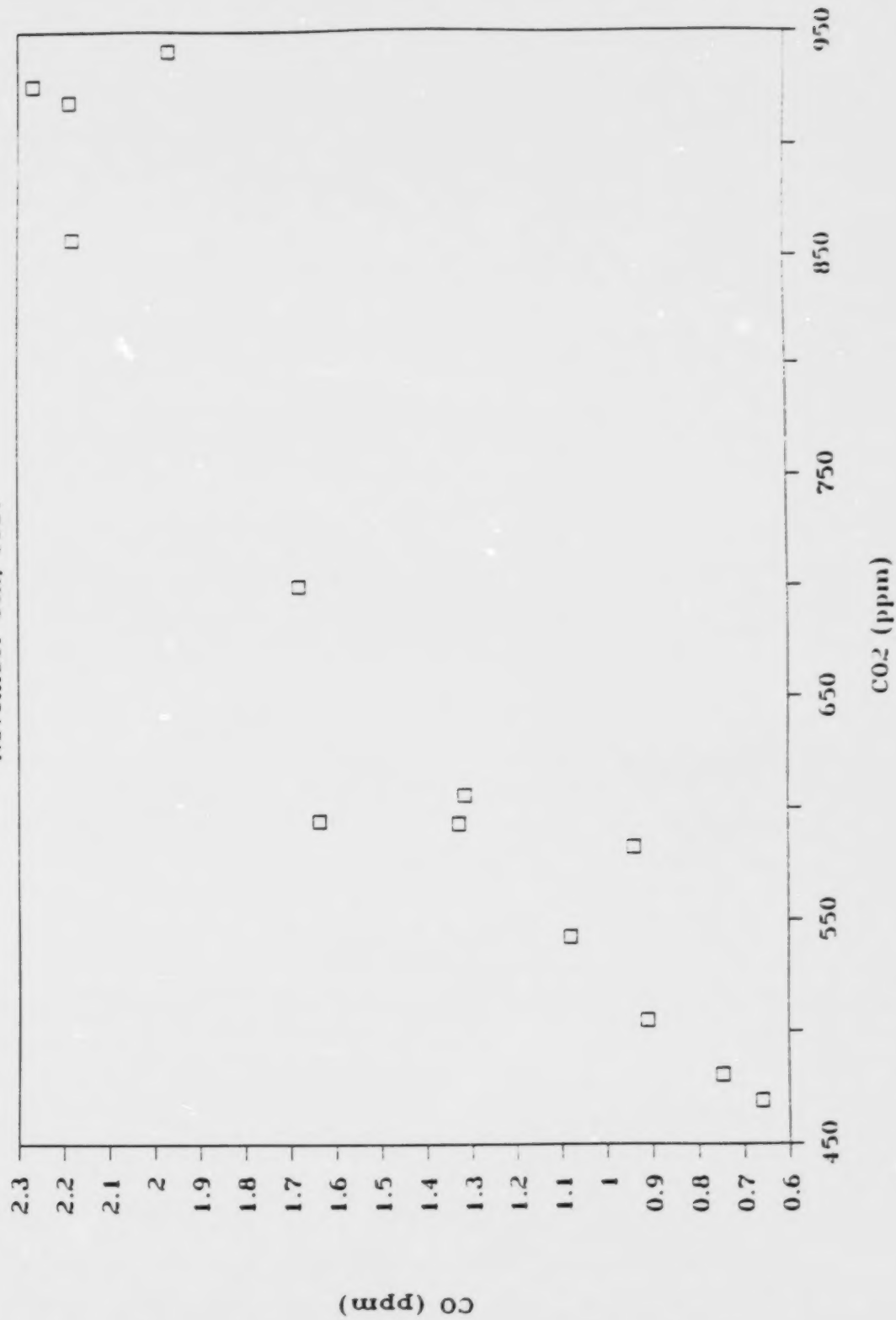
1000 LEVEL AVG. EXH. CORRELATION

November 5, 1987



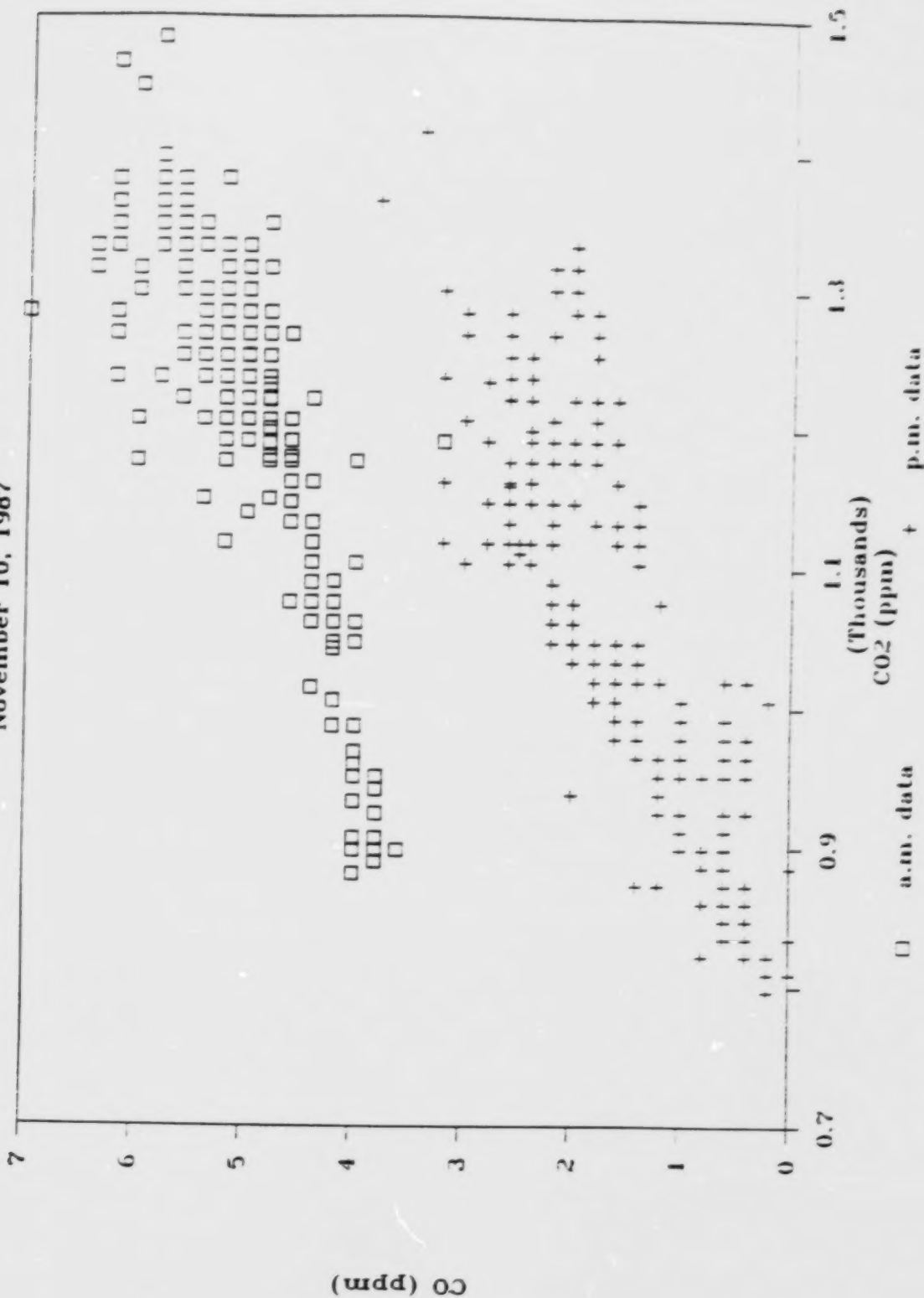
1000 LEVEL AVG. EXH. CORRELATION

November 6th, 1987



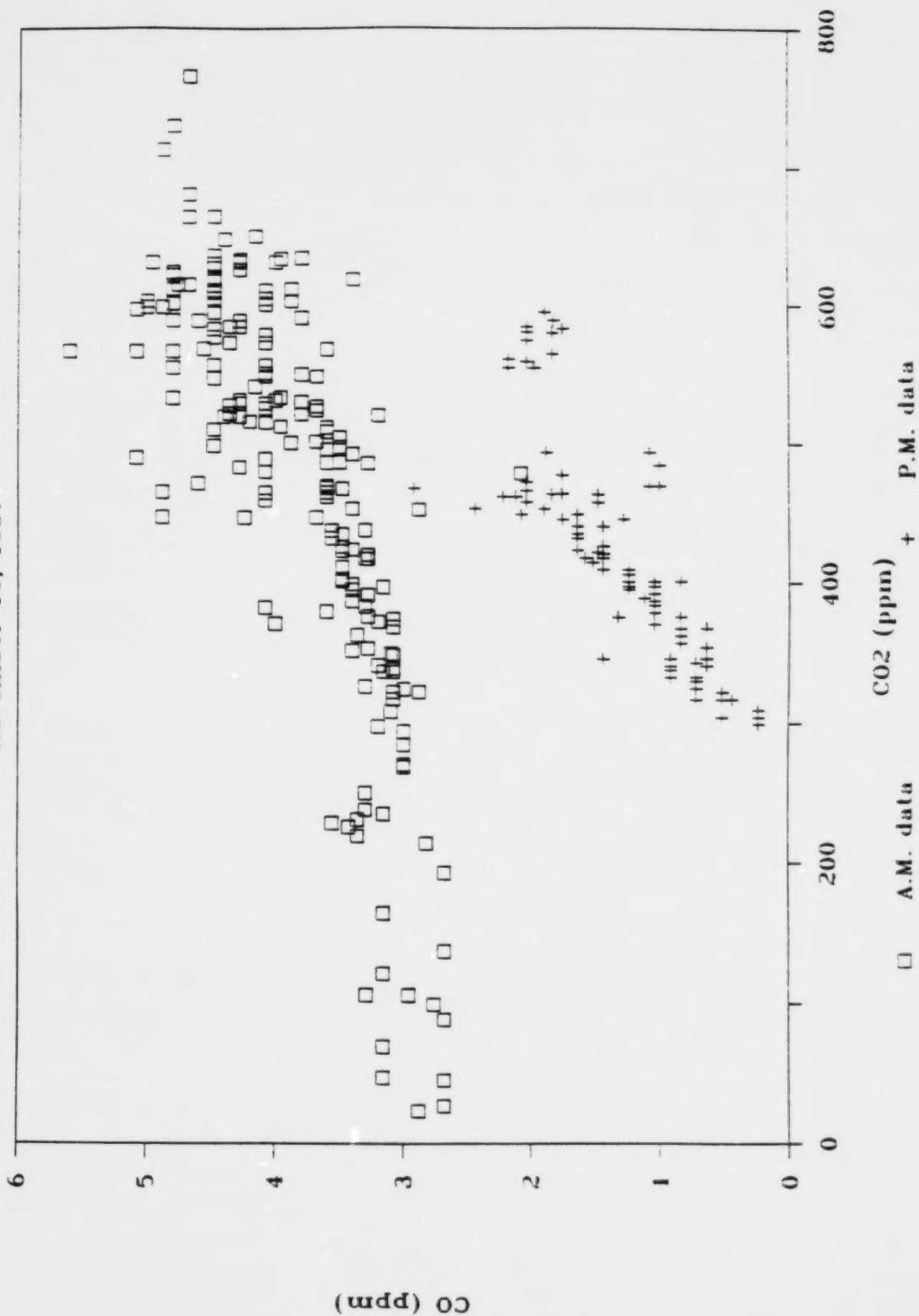
725 LEVEL EXH. CORRELATION

November 10, 1987



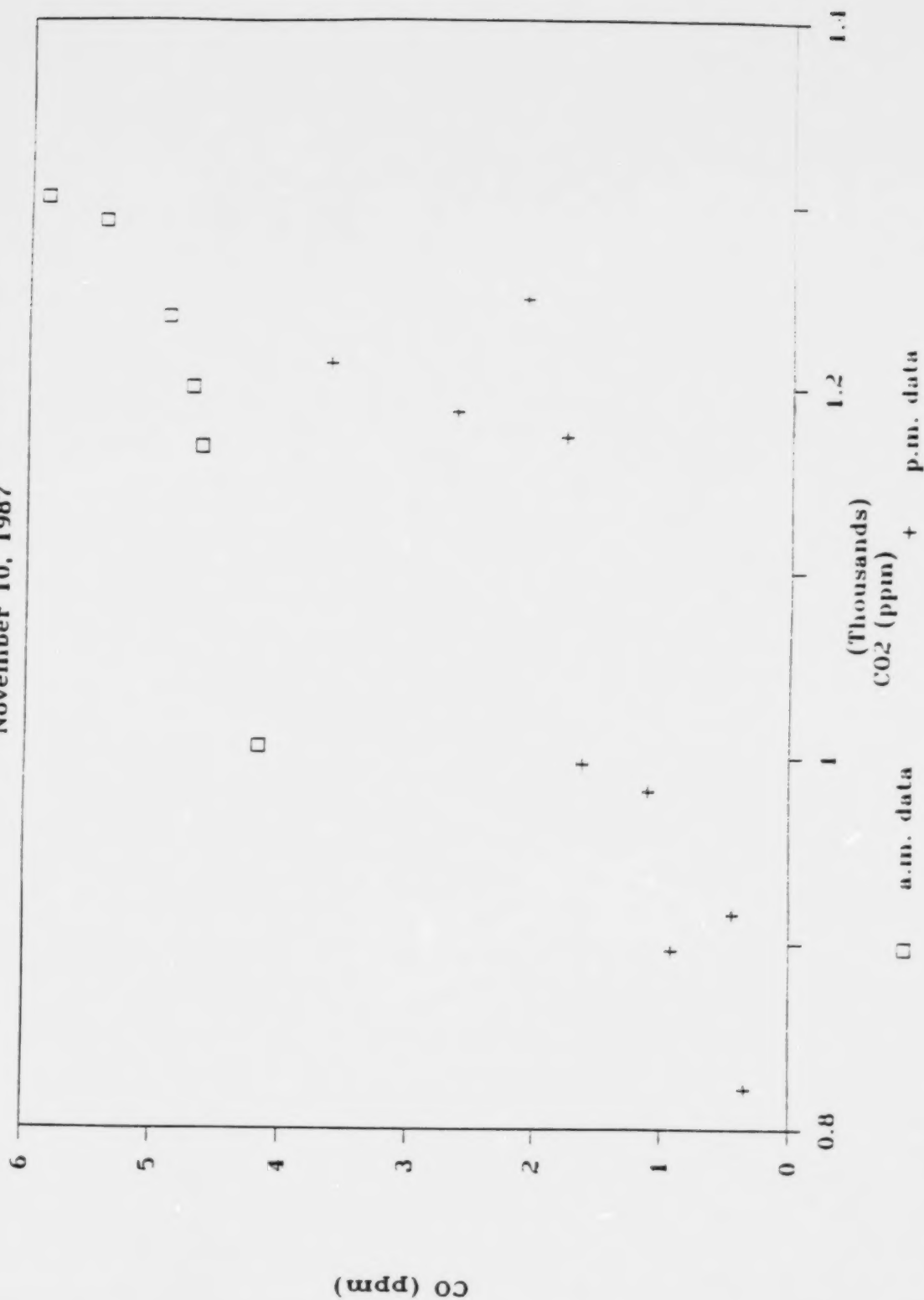
725 LEVEL CORR. EXH. CORRELATION

November 10, 1987



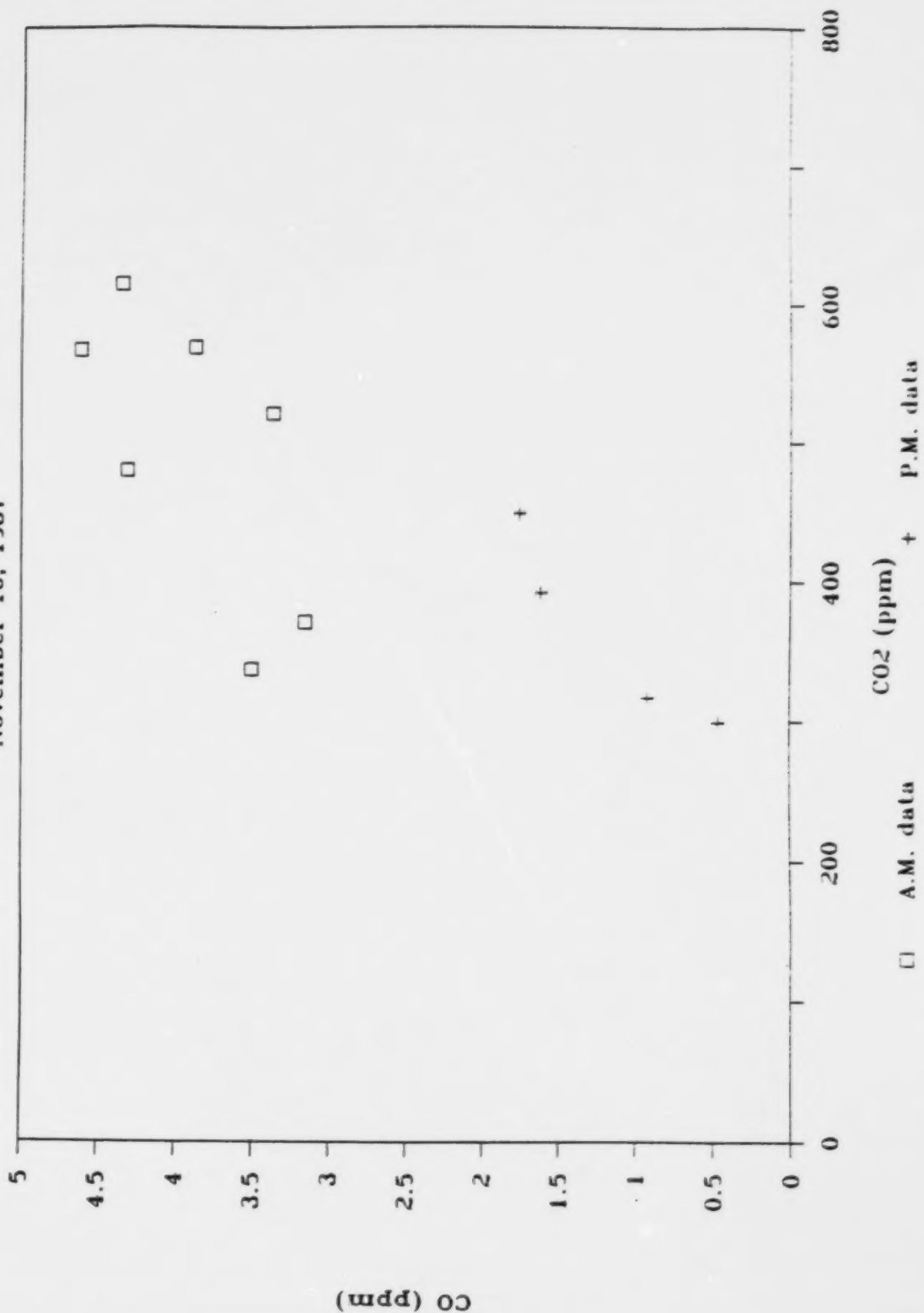
725 LEVEL AVG. EXH. CORRELATION

November 10, 1987



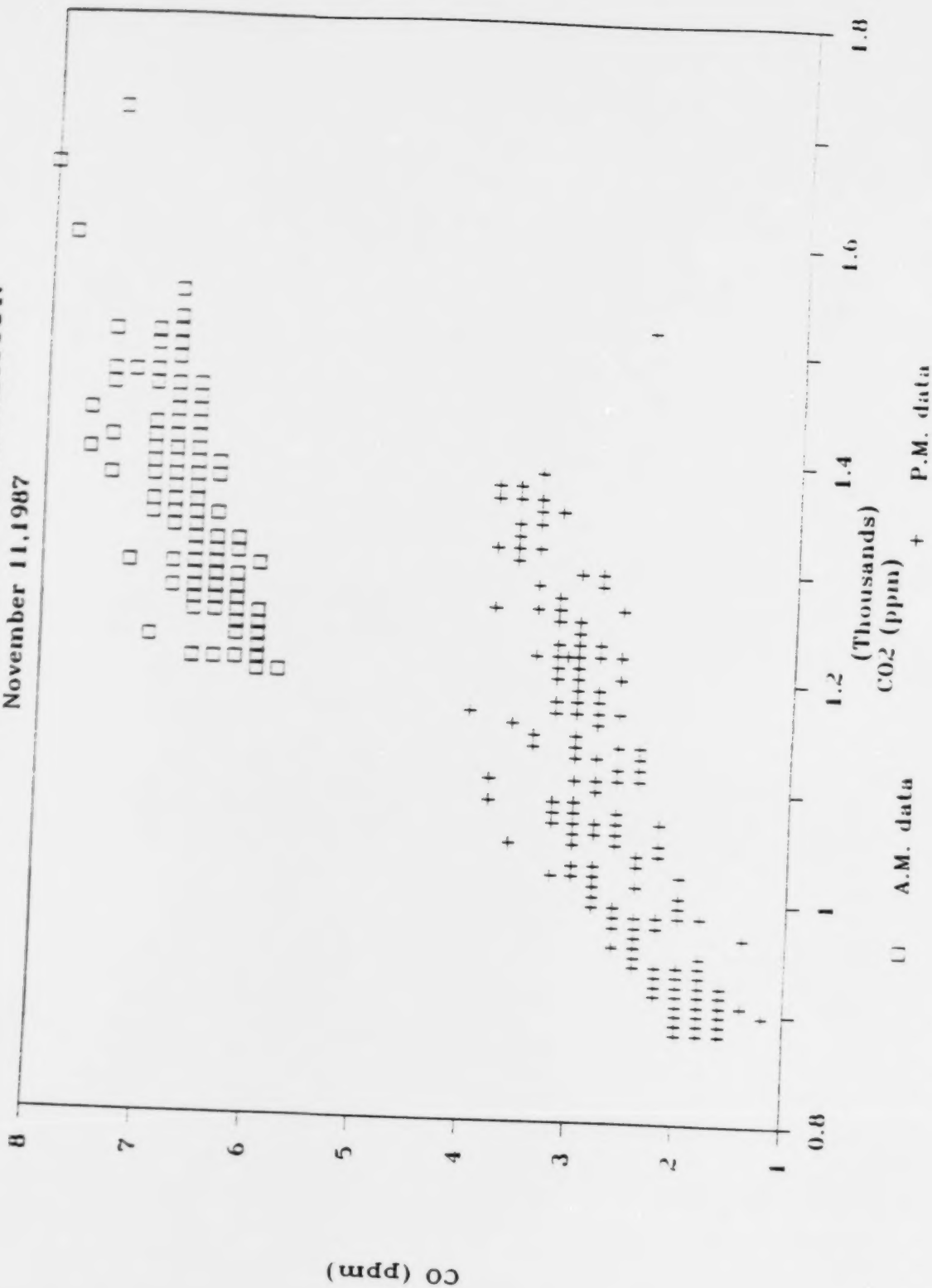
725 LEVEL CORR. AVG. EXH. CORRELATION

November 10, 1987



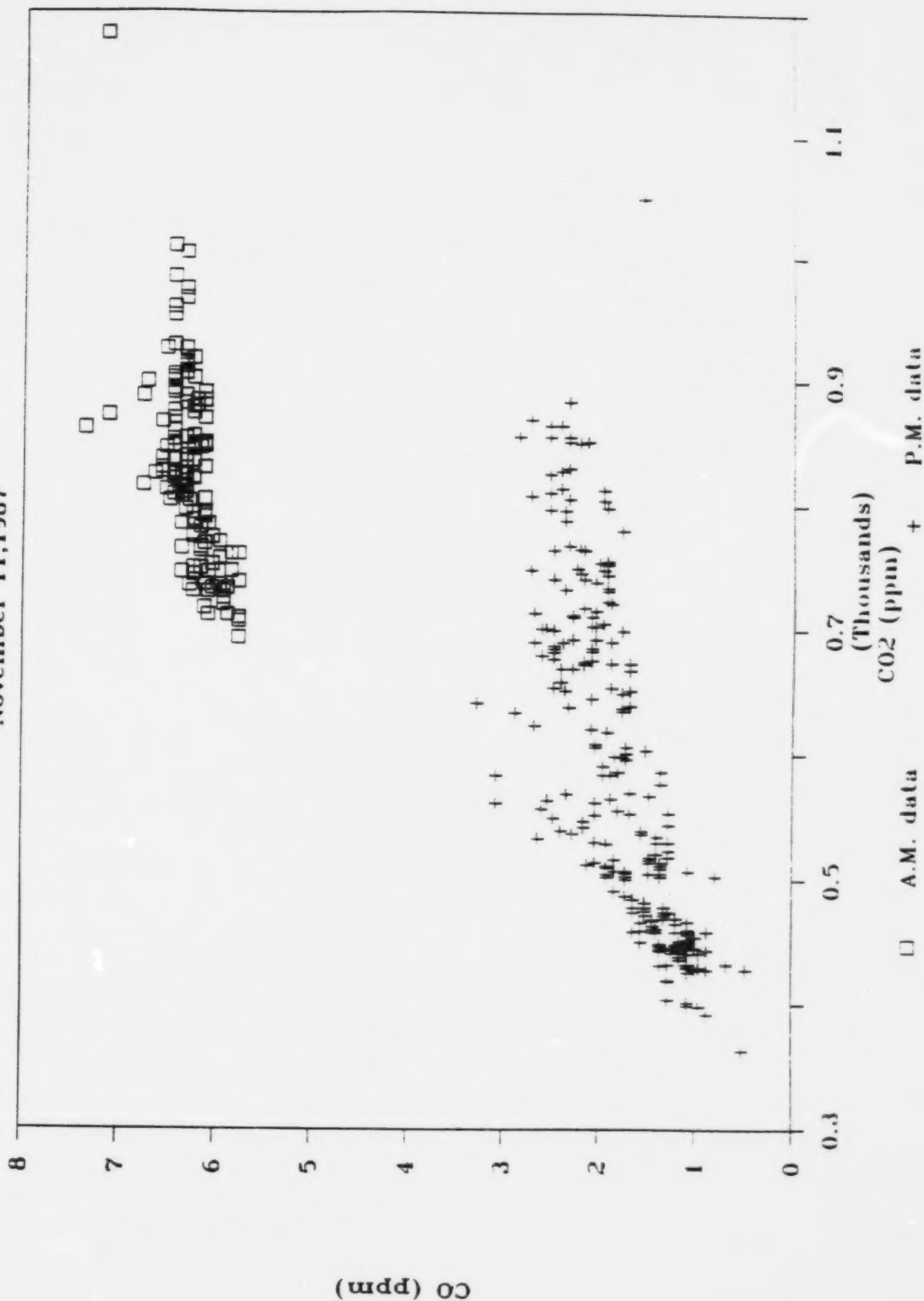
725 LEVEL EXH. CORRELATION

November 11, 1987



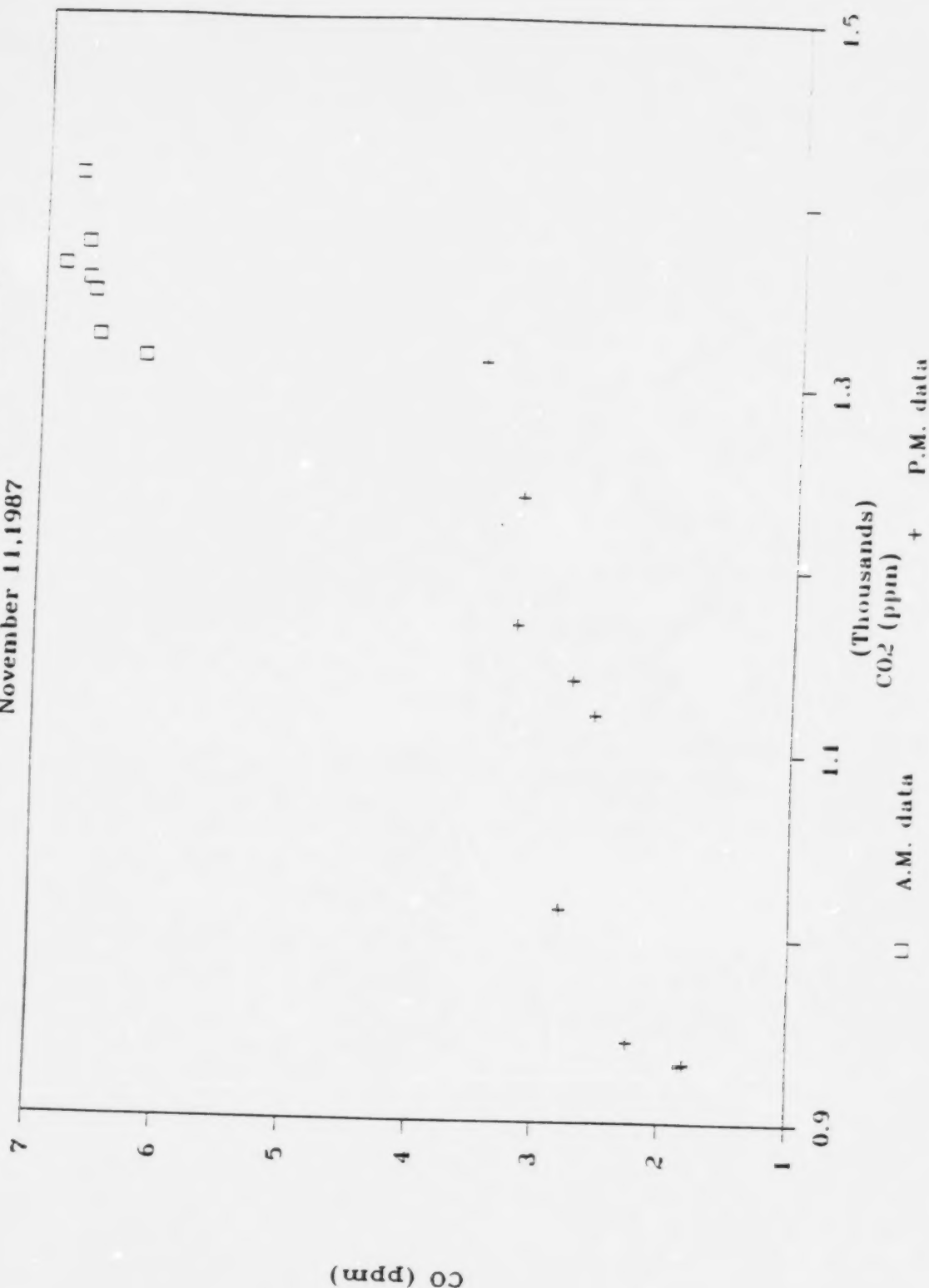
725 LEVEL CORR. EXH. CORRELATION

November 11, 1987



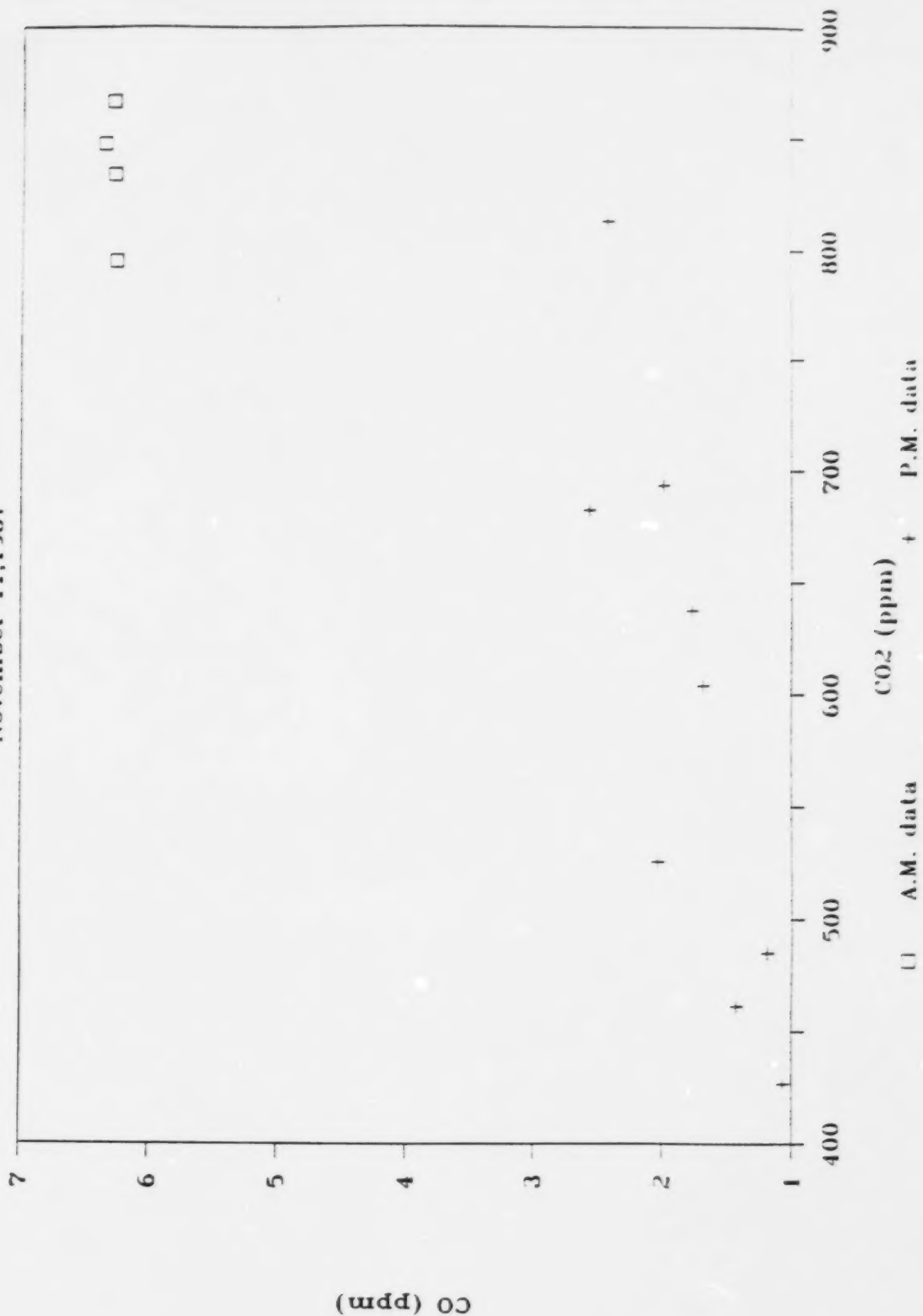
725 LEVEL AVG. EXH. CORRELATION

November 11, 1987



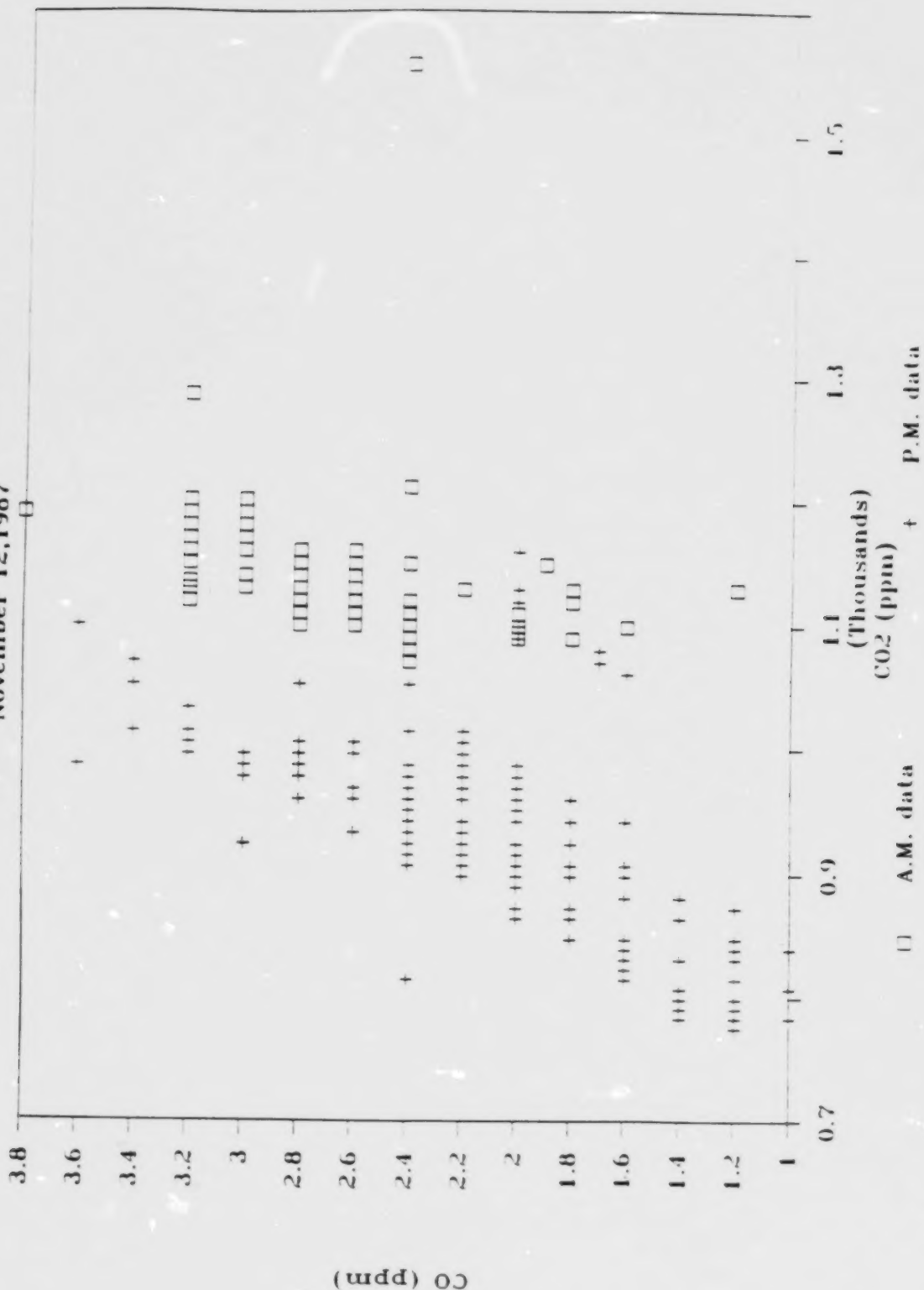
725 LEVEL CORR. AVG. EXH. CORRELATION

November 11, 1987



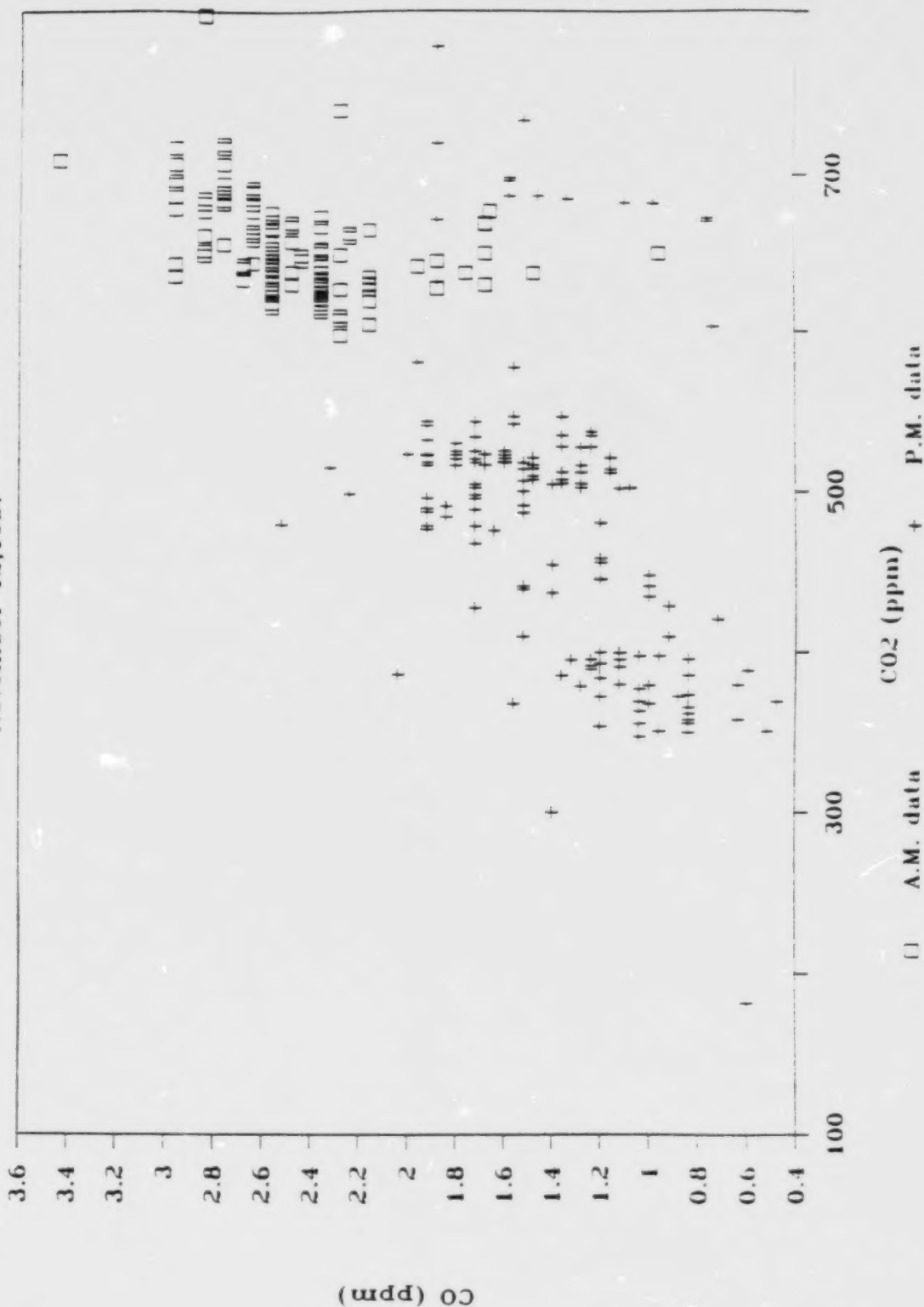
725 LEVEL EXH. CORRELATION

November 12, 1987



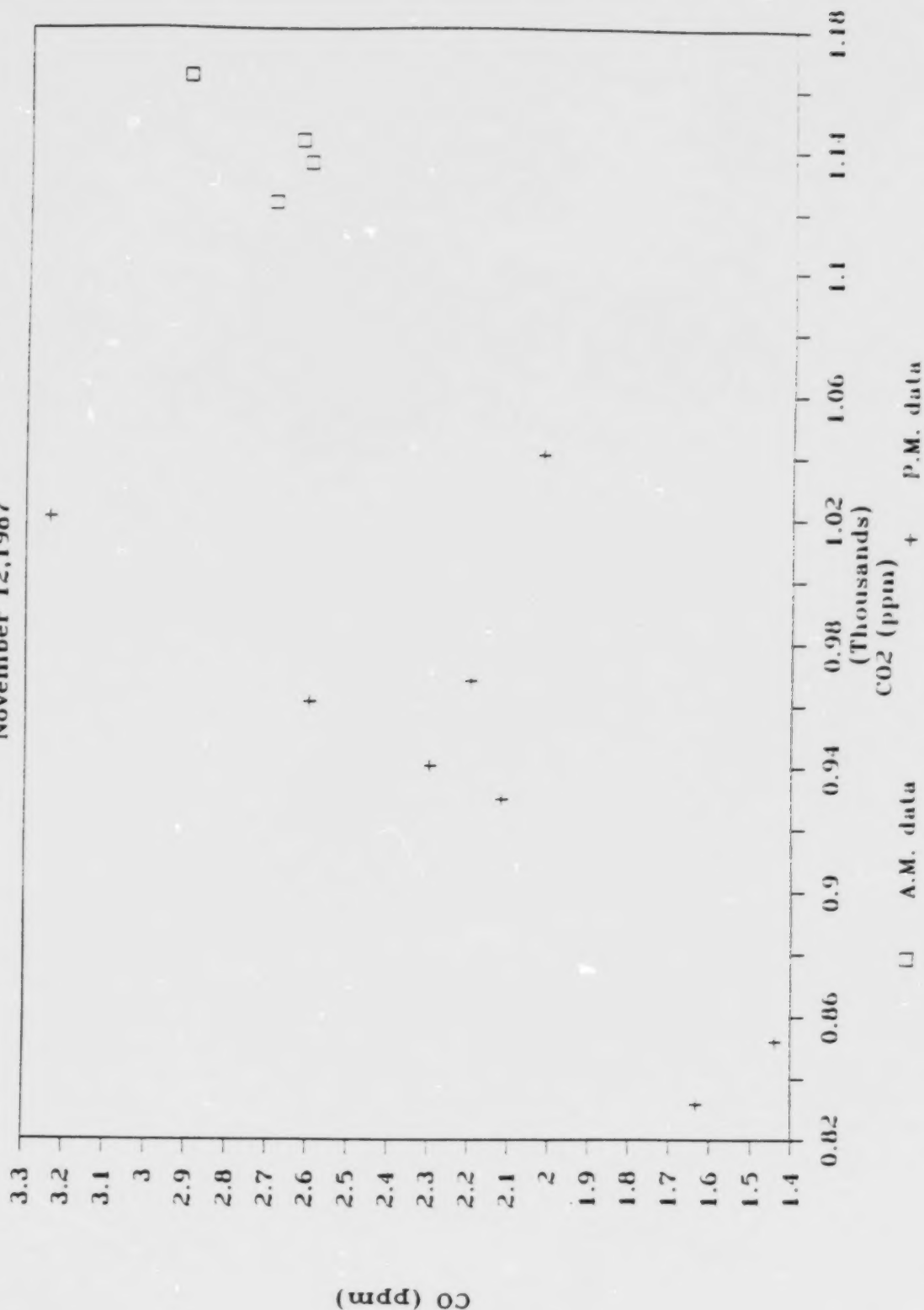
725 LEVEL CORR. EXH. CORRELATION

November 12, 1987



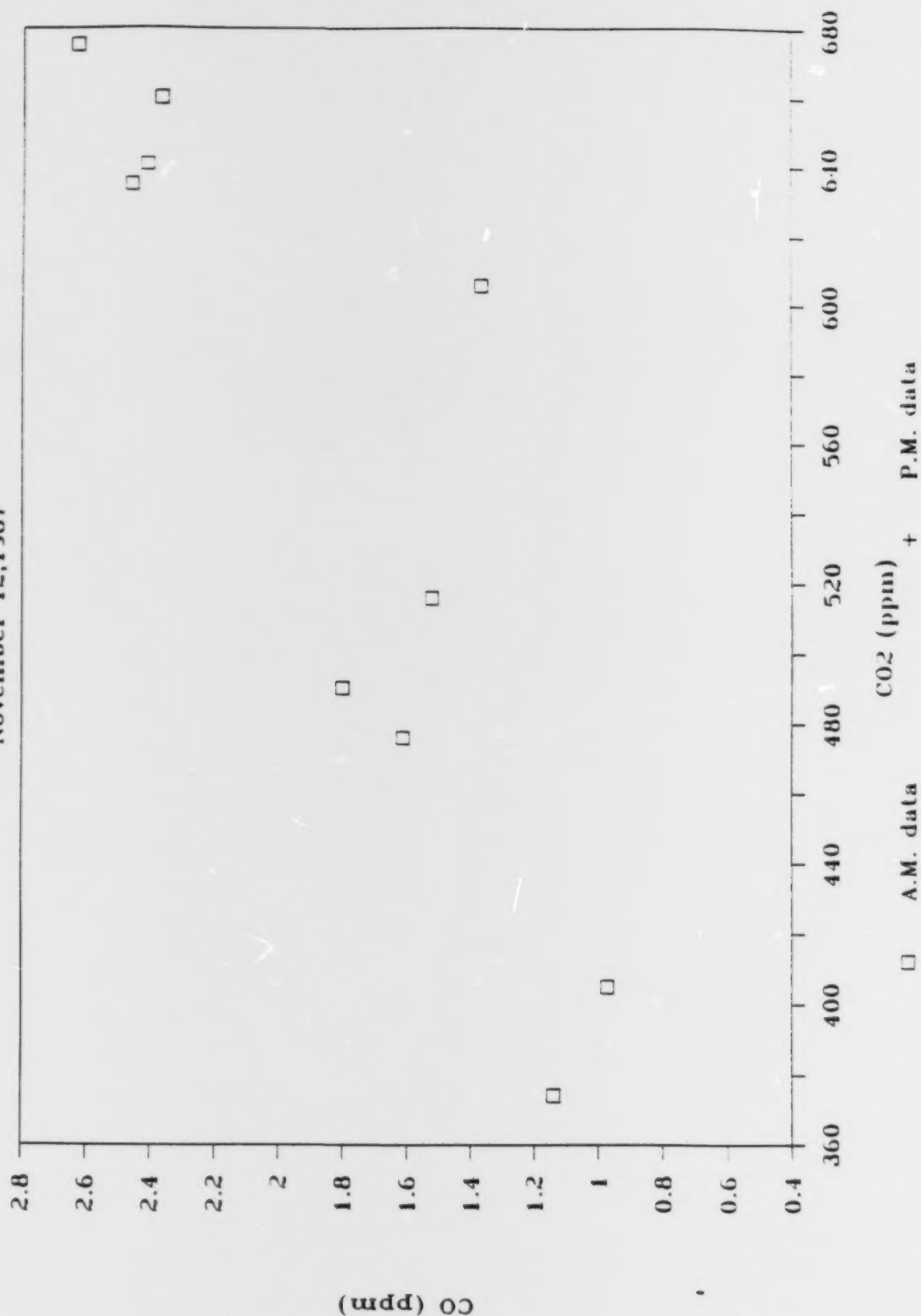
725 LEVEL AVG. EXH. CORRELATION

November 12, 1987



725 LEVEL CORR. AVG. EXH. CORRELATION

November 12, 1987

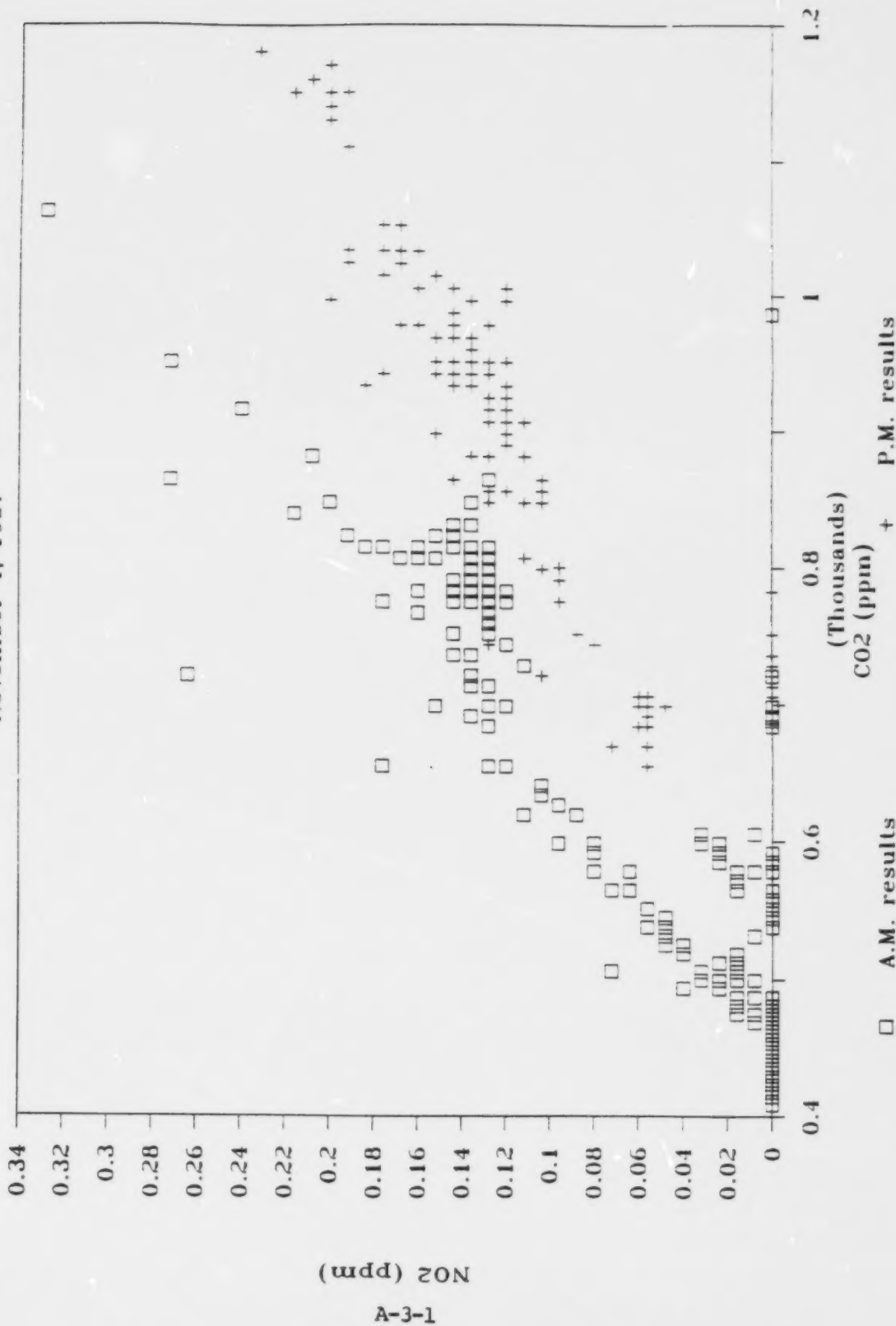


APPENDIX A-3

NO₂ vs CO₂

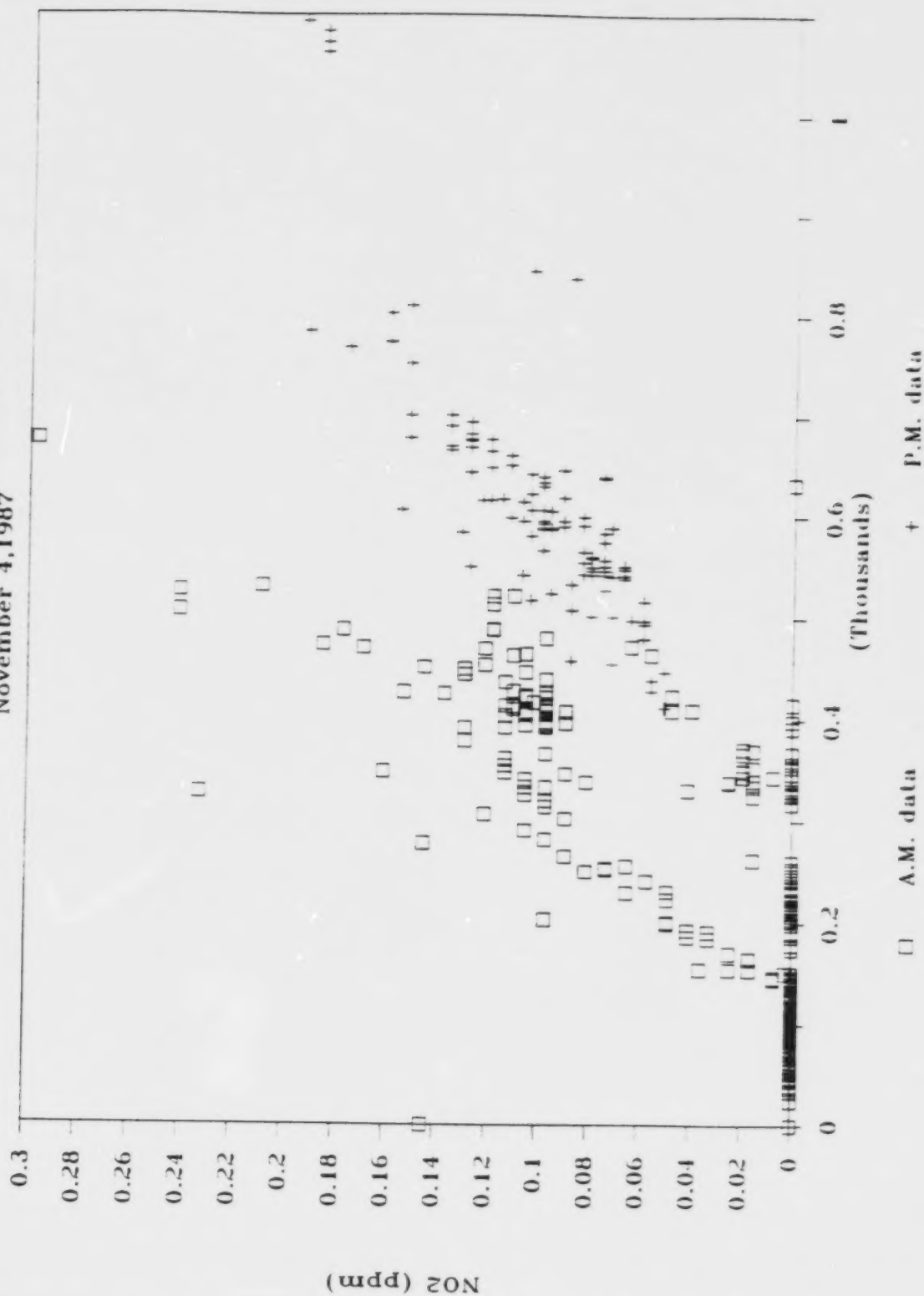
1000 LEVEL EXH. CORRELATION

November 4, 1987



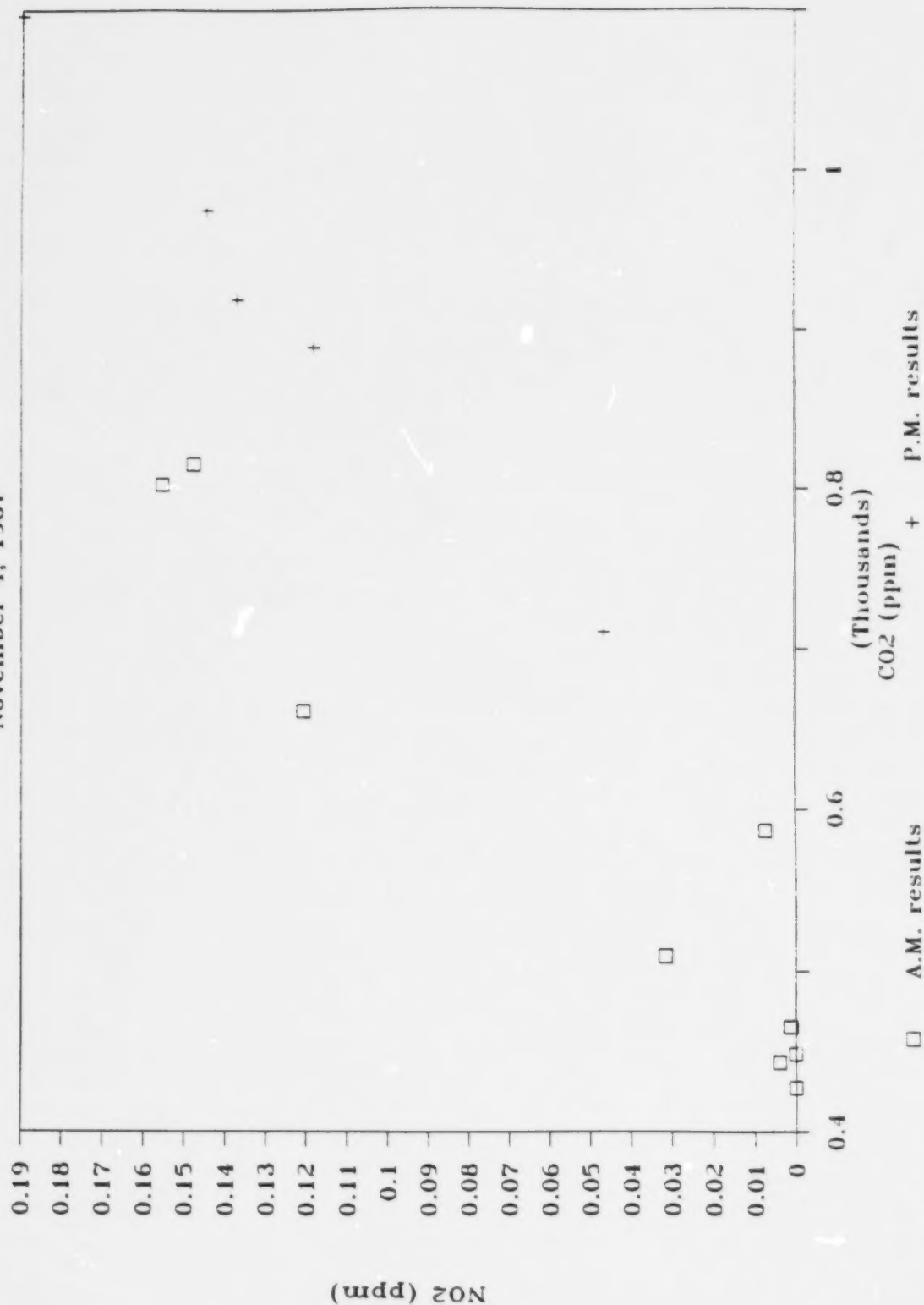
1000 LEVEL EXH. CORRELATION

November 4, 1987



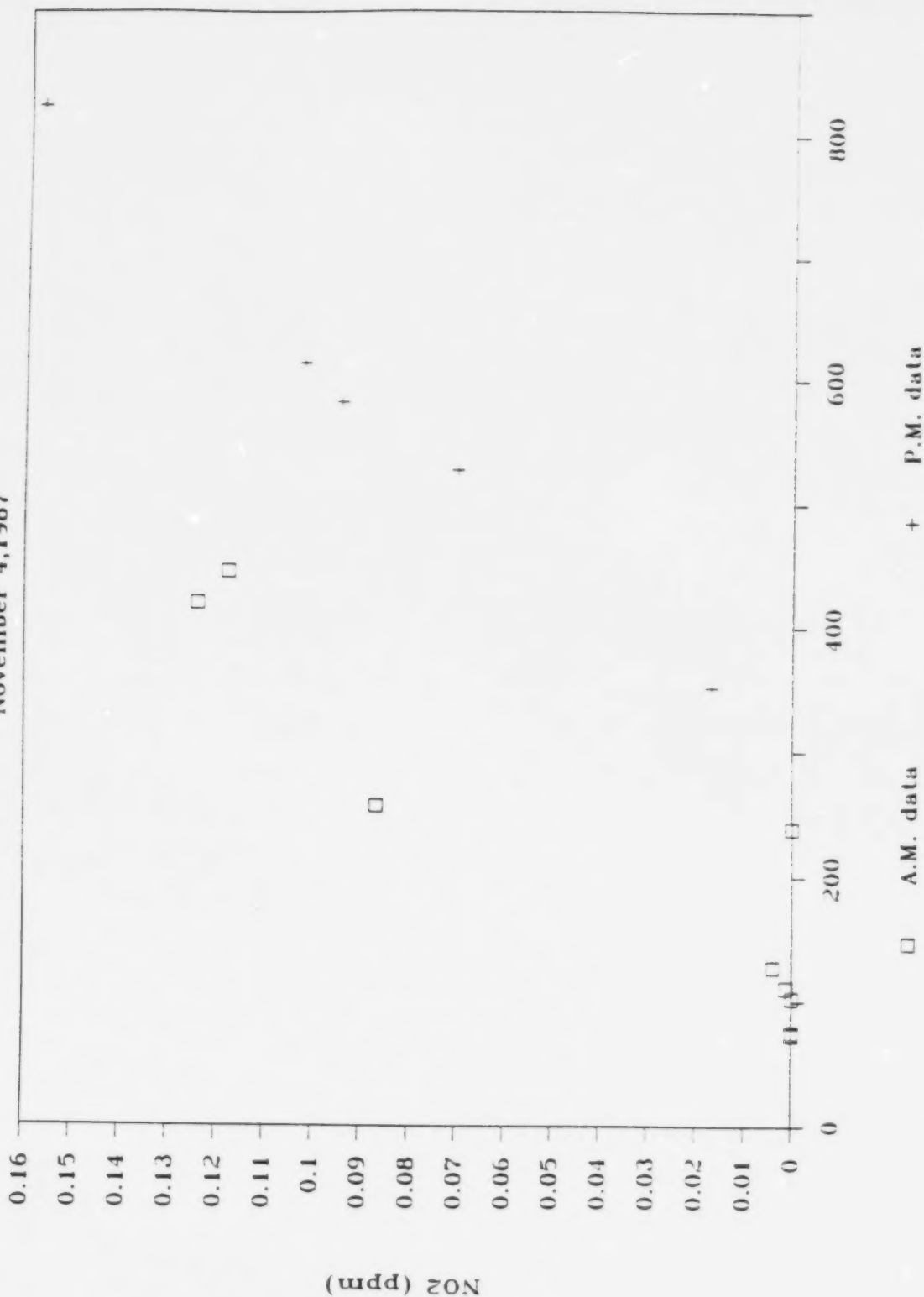
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



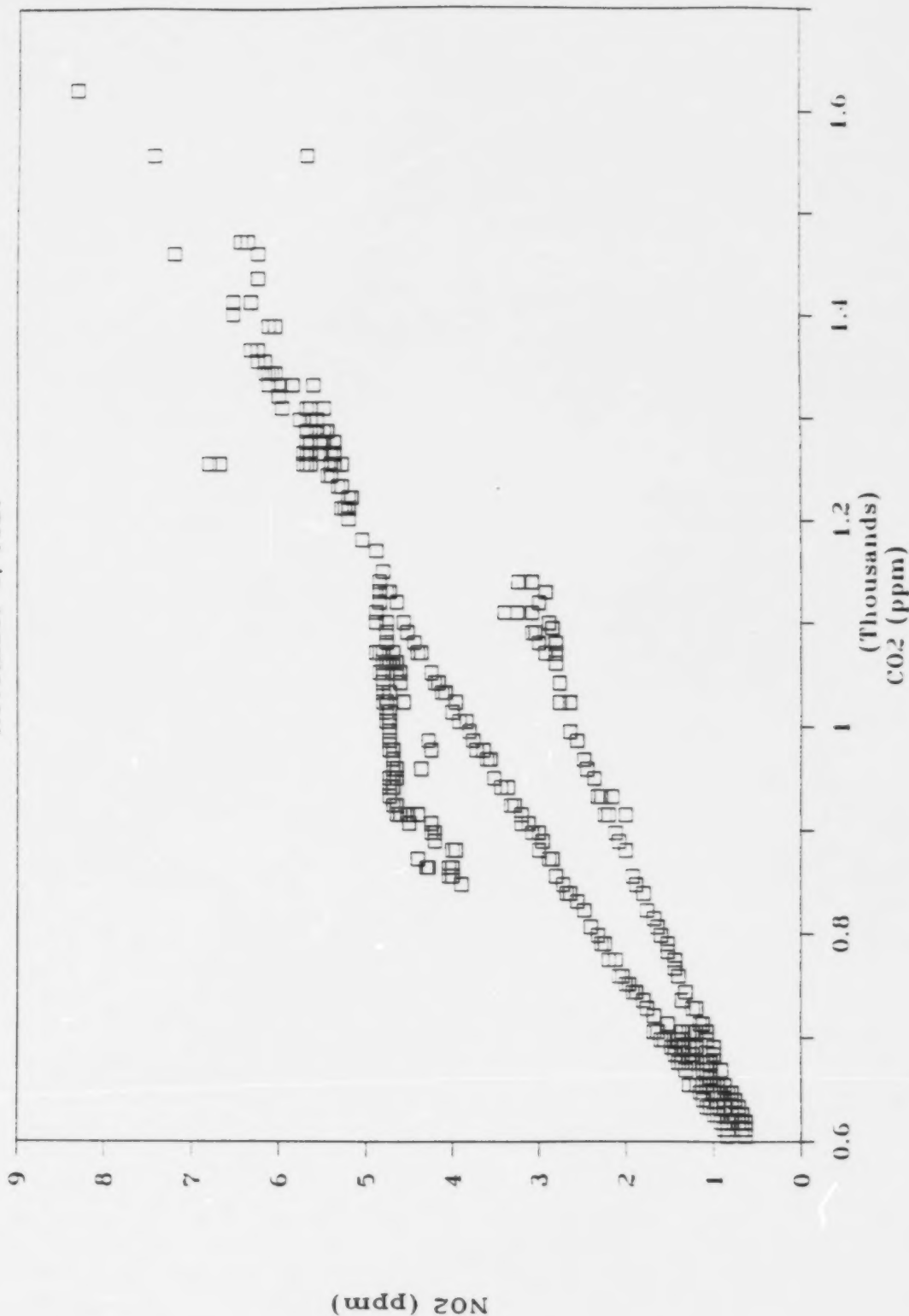
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



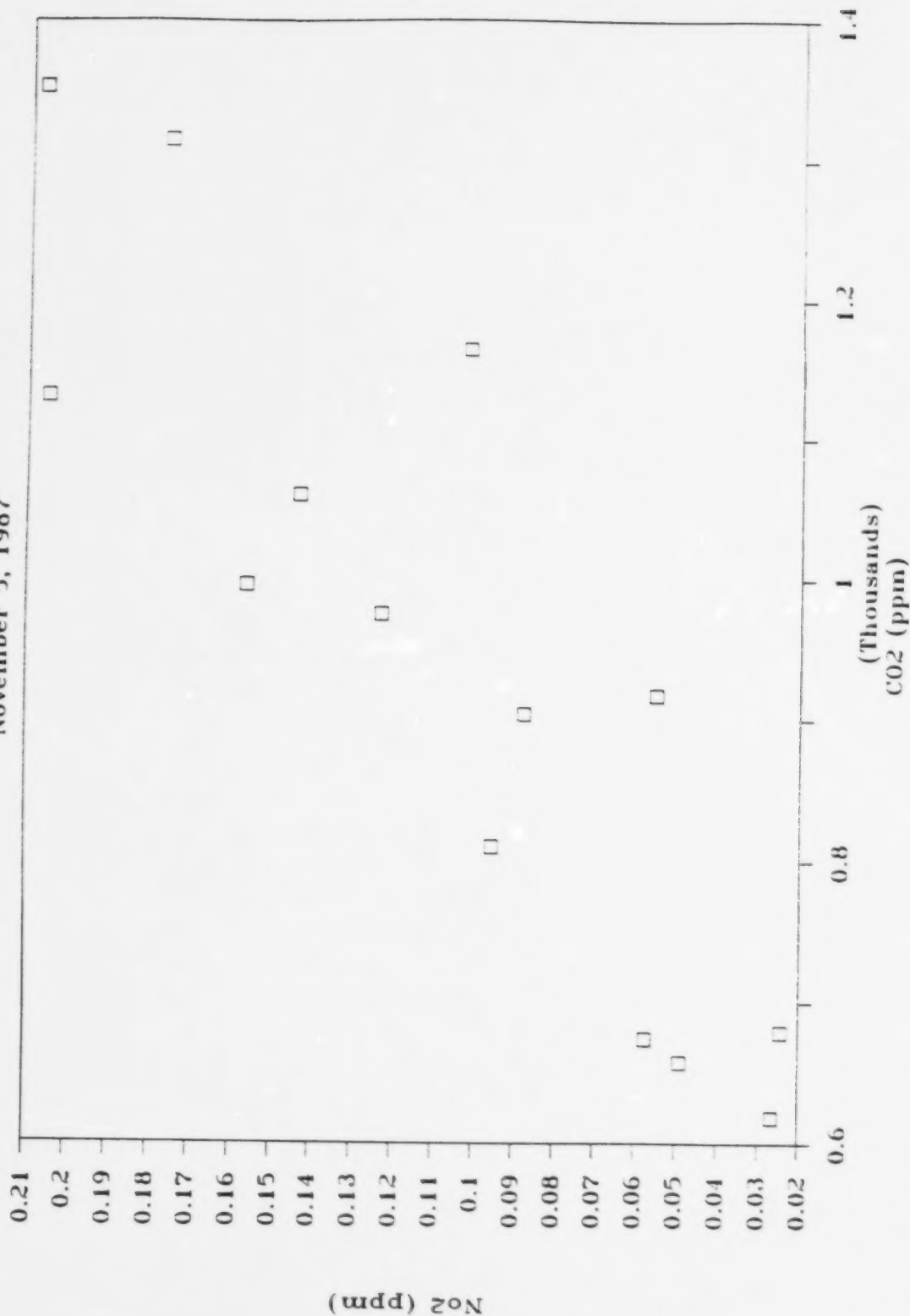
1000 LEVEL EXH. CORRELATION

November 5, 1987



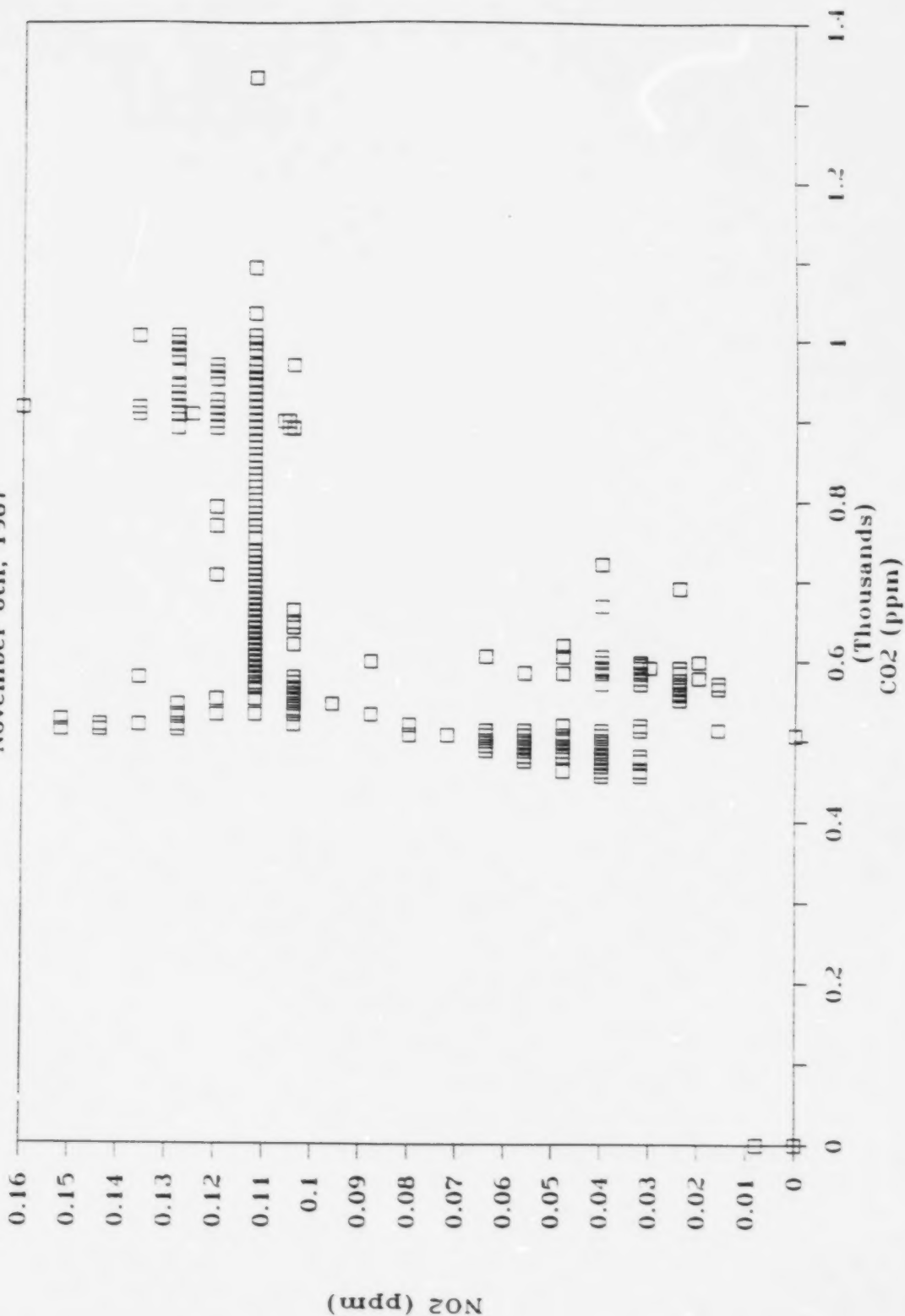
1000 LEVEL AVG. EXH. CORRELATION

November 5, 1987



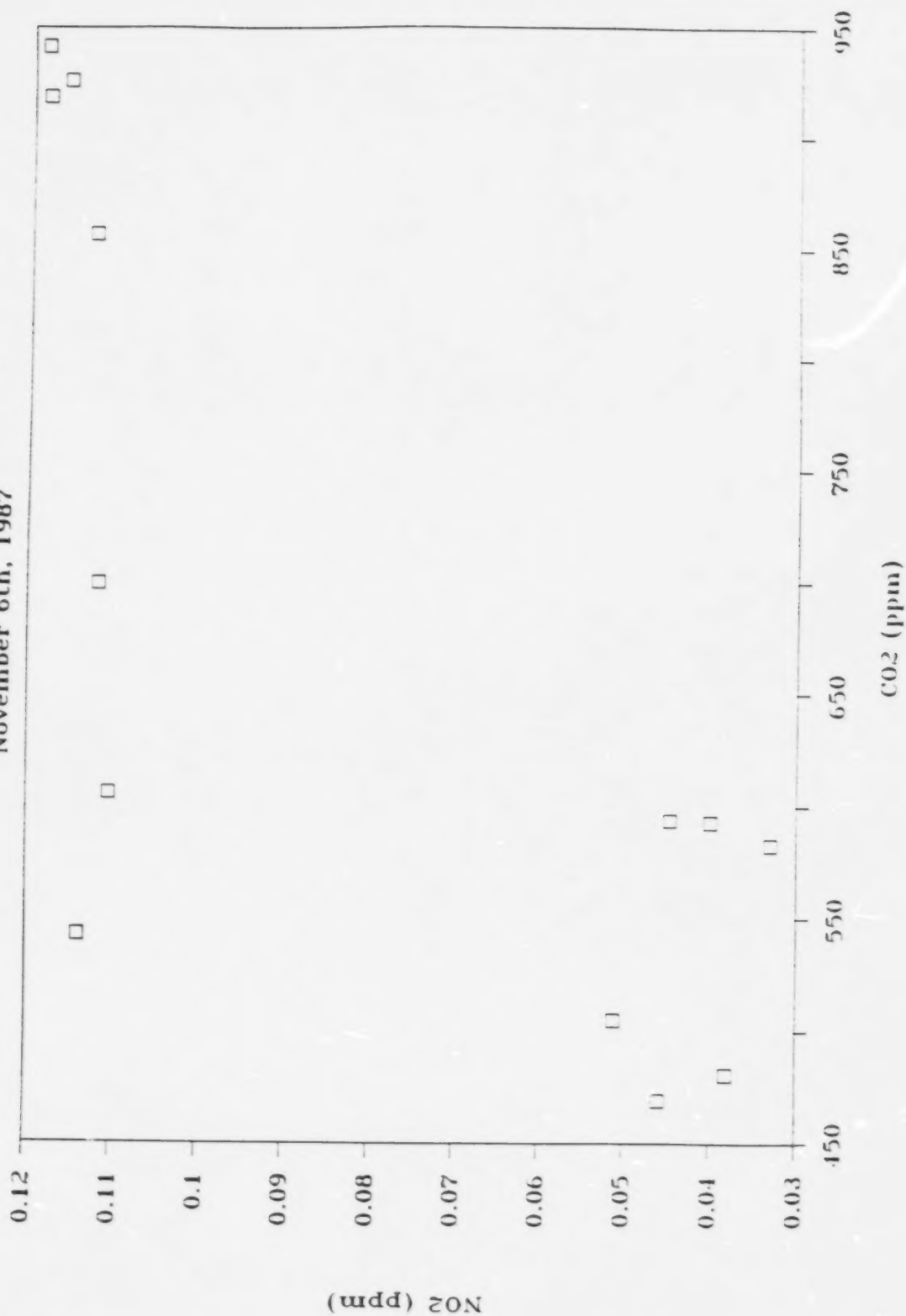
1000 LEVEL EXH. CORRELATION

November 6th, 1987



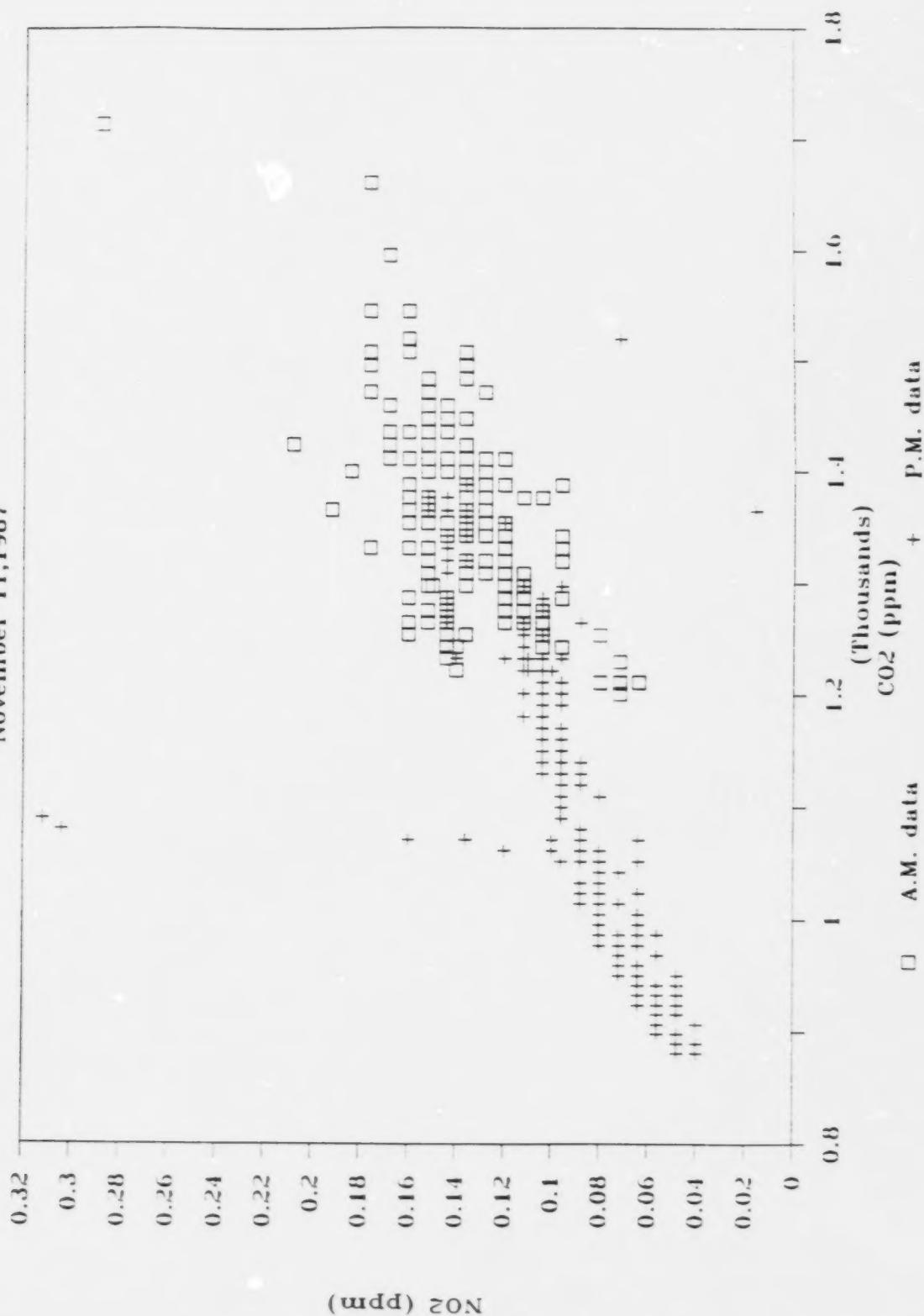
1000 LEVEL AVG. EXH. CORRELATION

November 6th, 1987



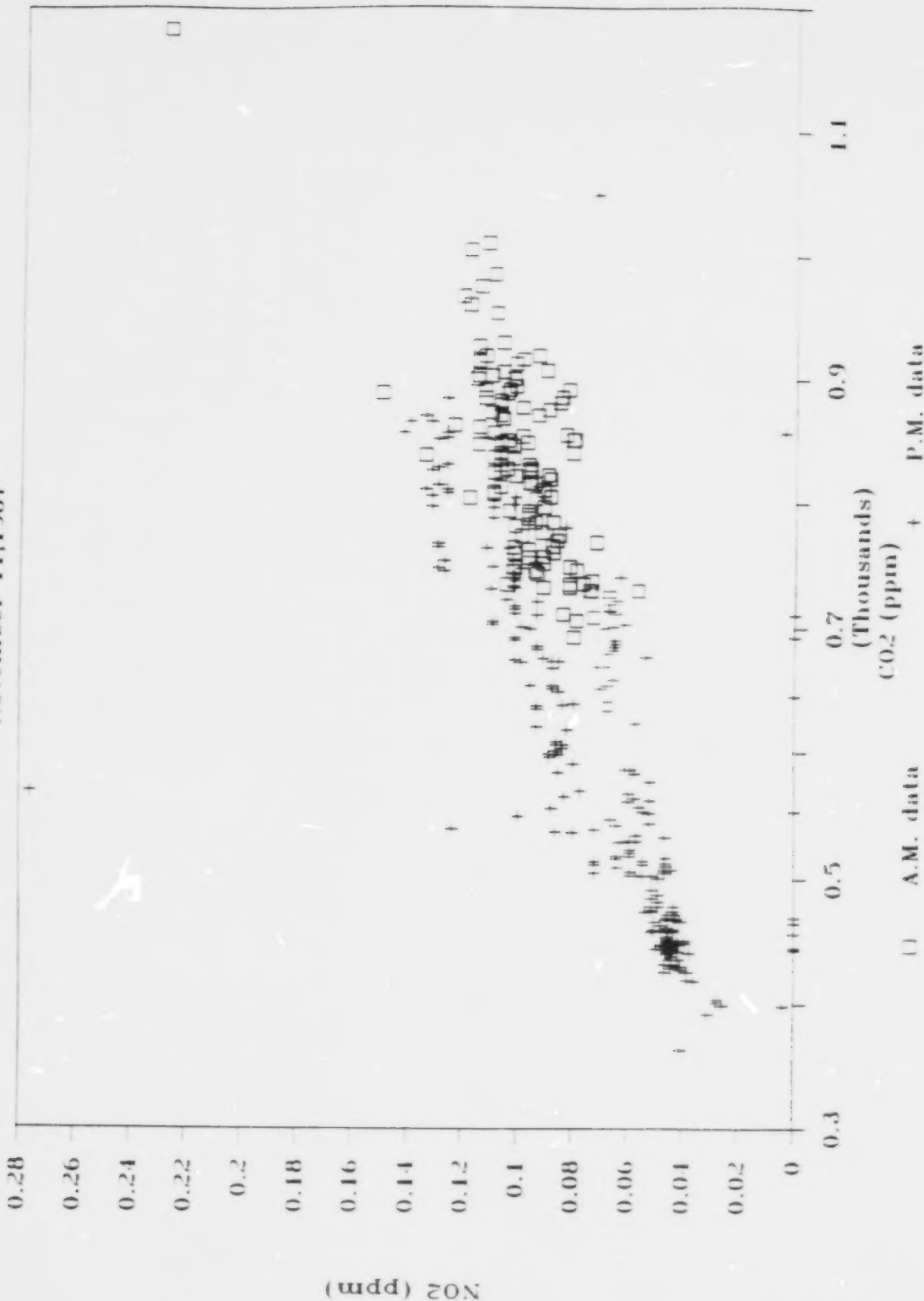
725 LEVEL EXH. CORRELATION

November 11, 1987



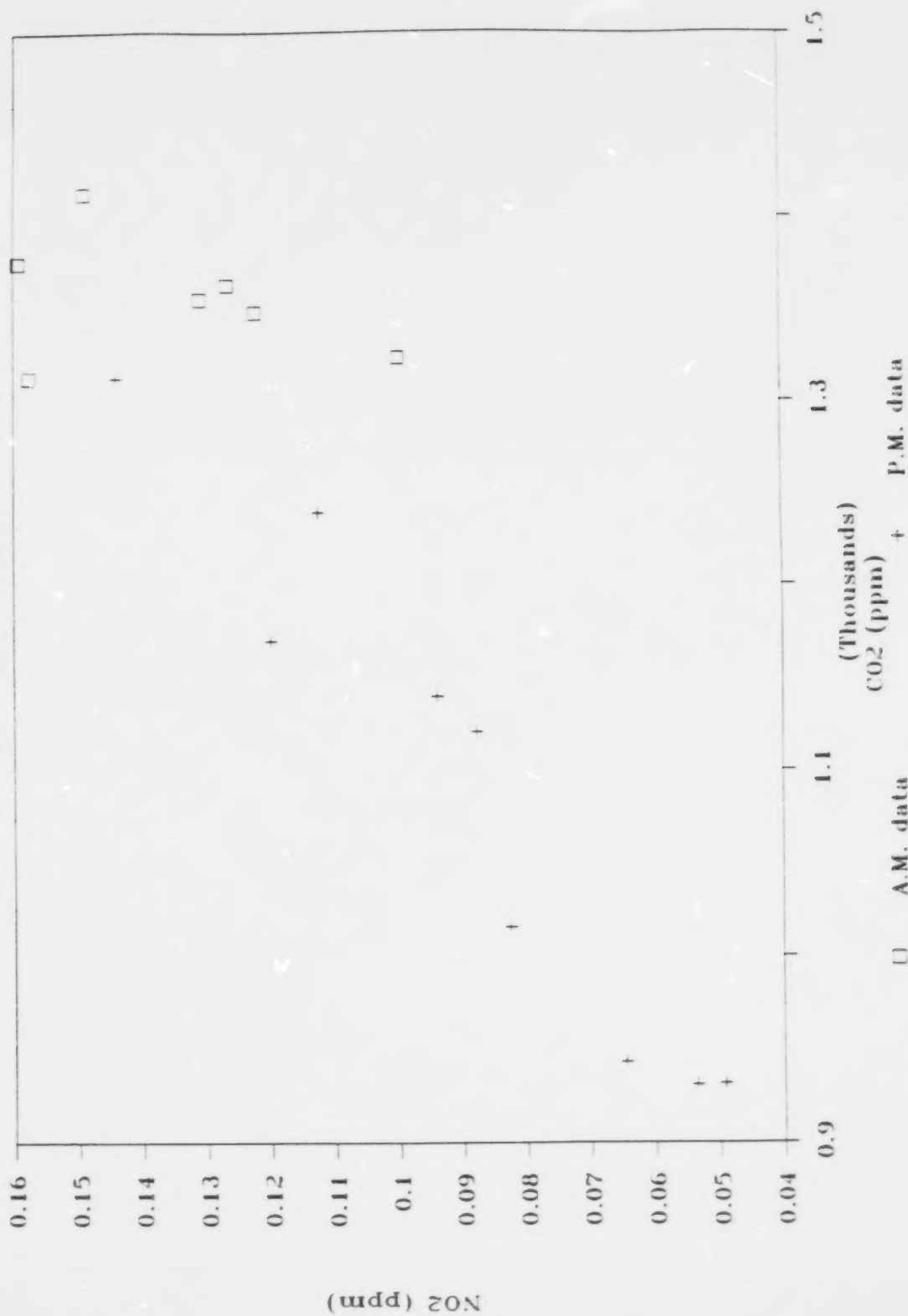
725 LEVEL CORR. EXH. CORRELATION

November 11, 1987



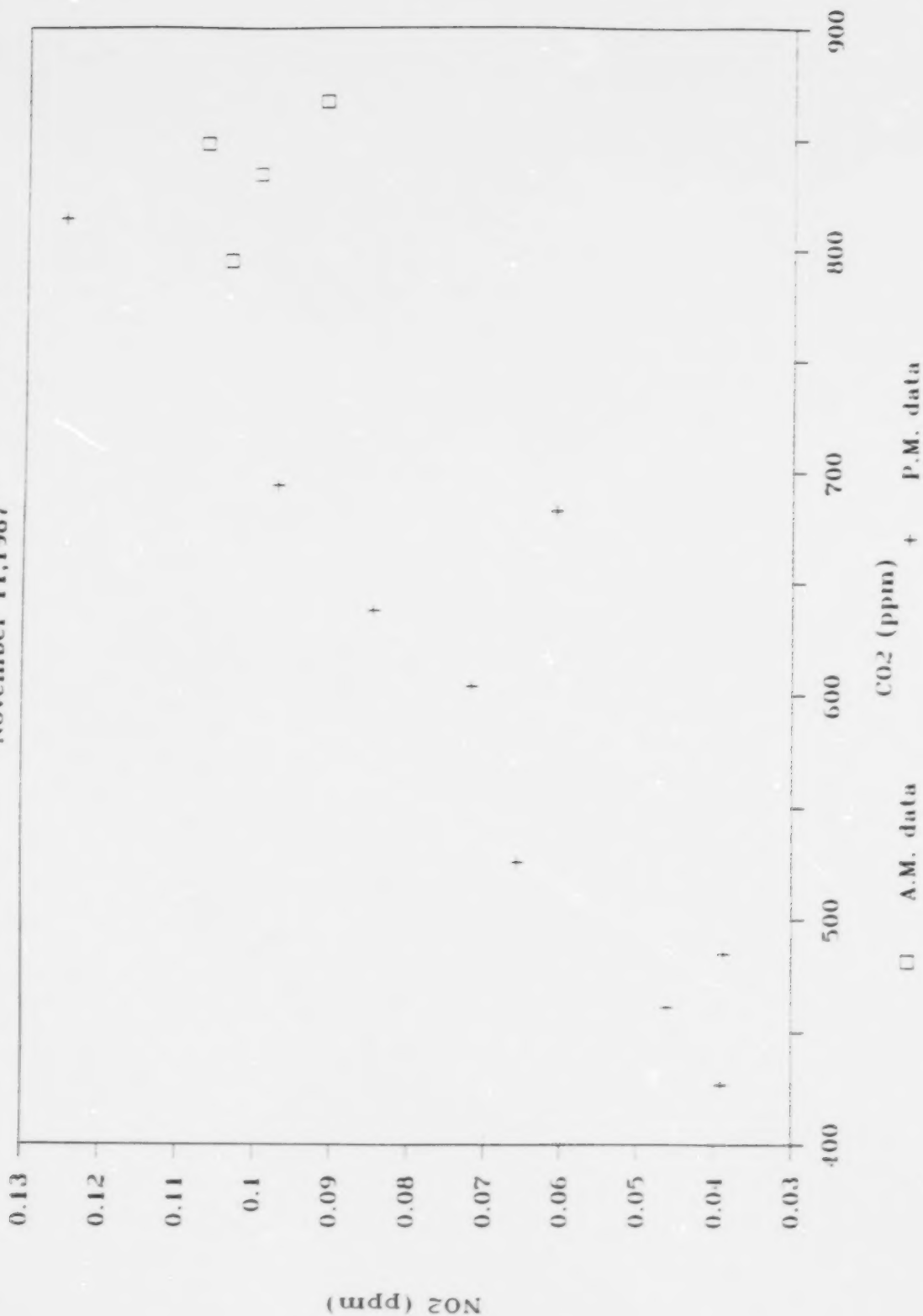
725 LEVEL AVG. EXH. CORRELATION

November 11, 1987



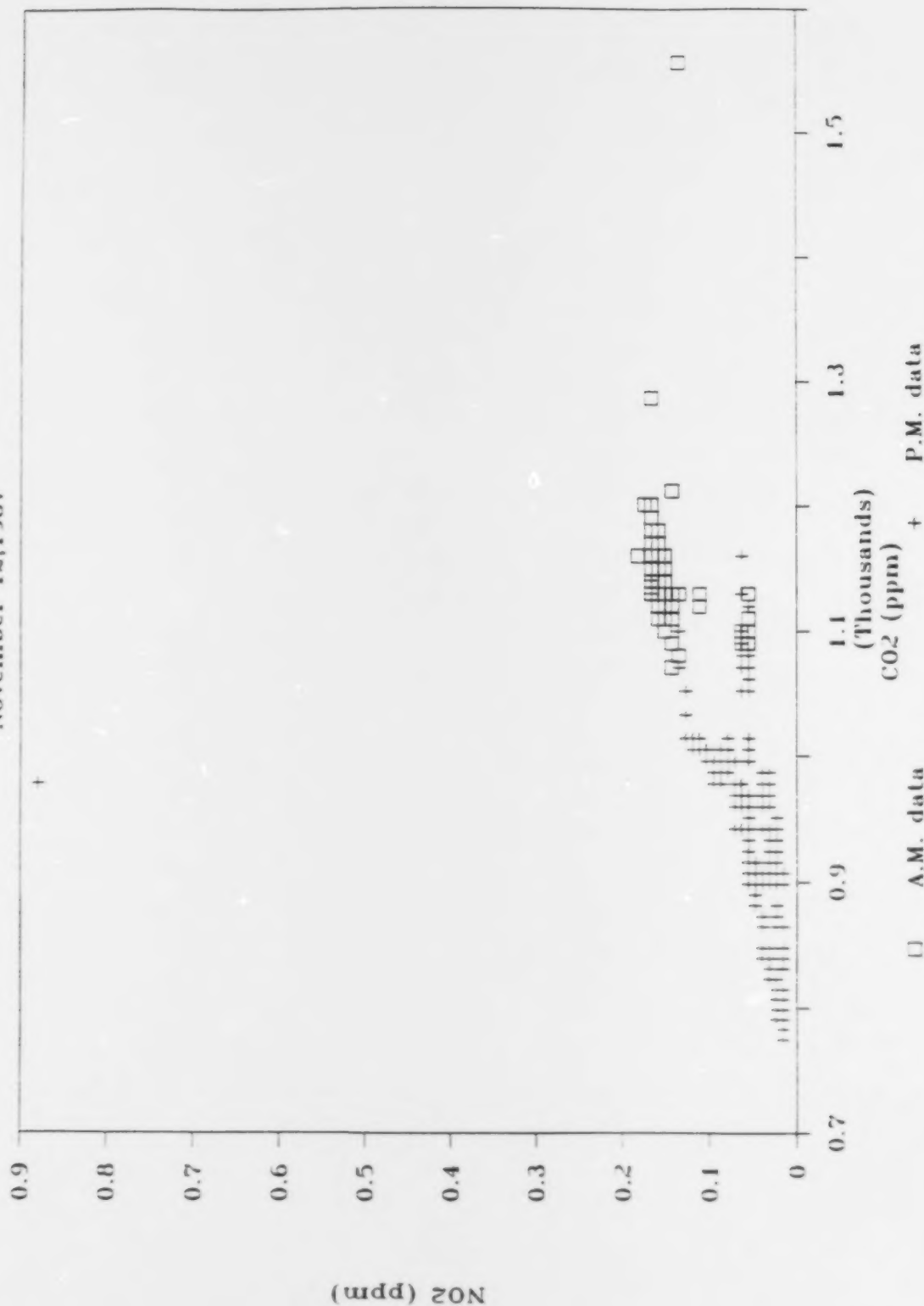
725 LEVEL CORR. EXH. CORRELATION

November 11, 1987



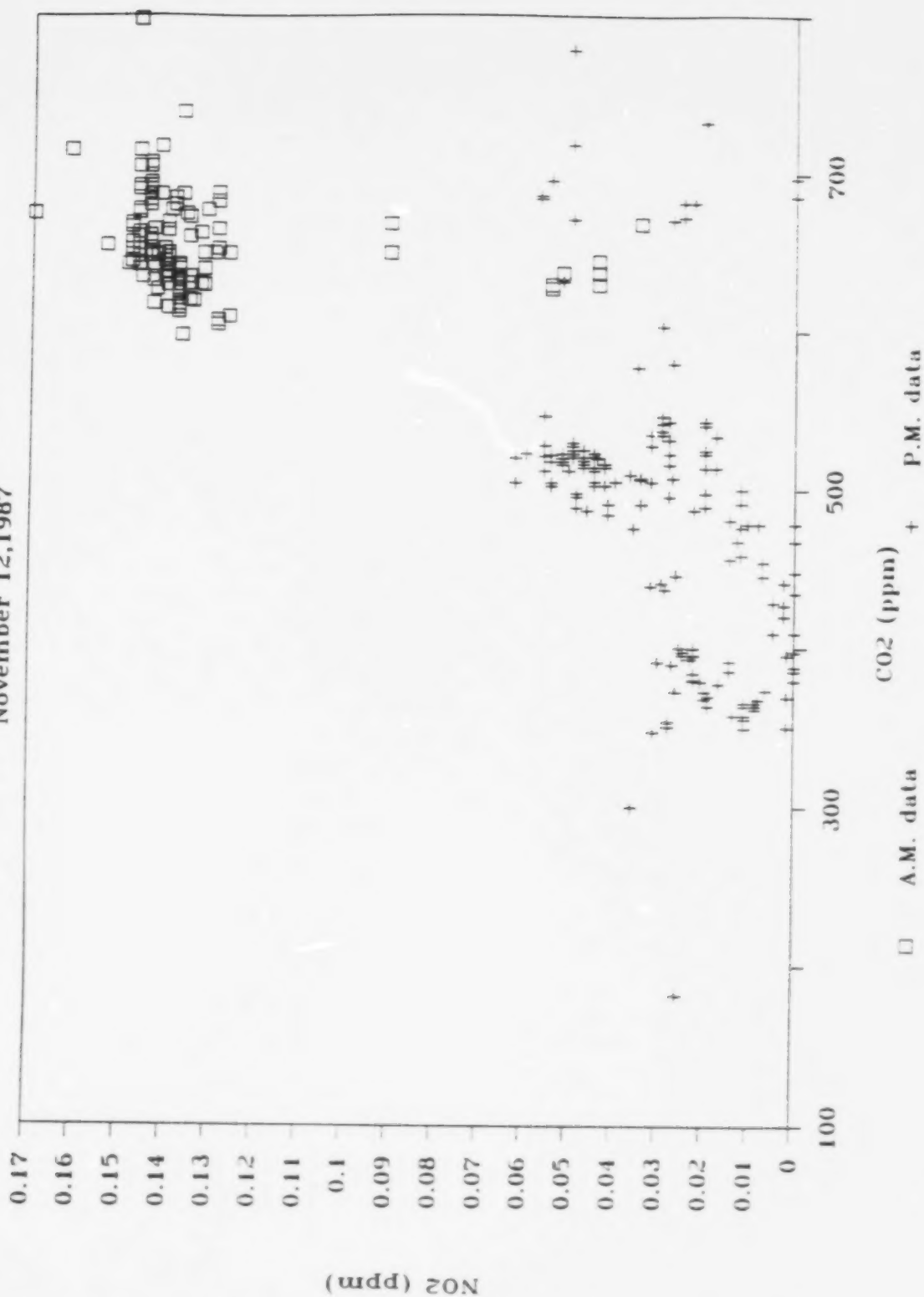
725 LEVEL EXH. CORRELATION

November 12, 1987



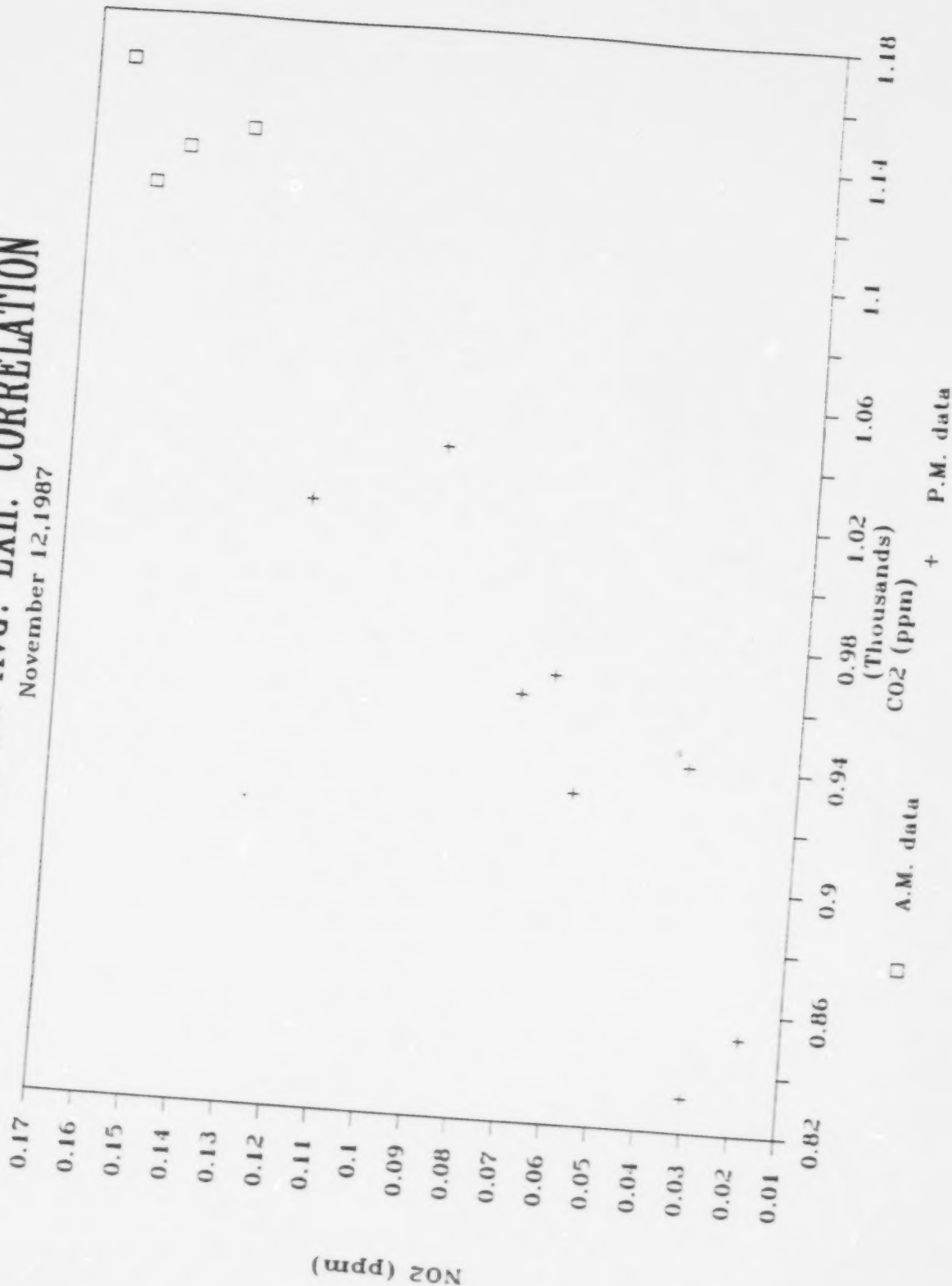
725 LEVEL CORR. EXH. CORRELATION

November 12, 1987



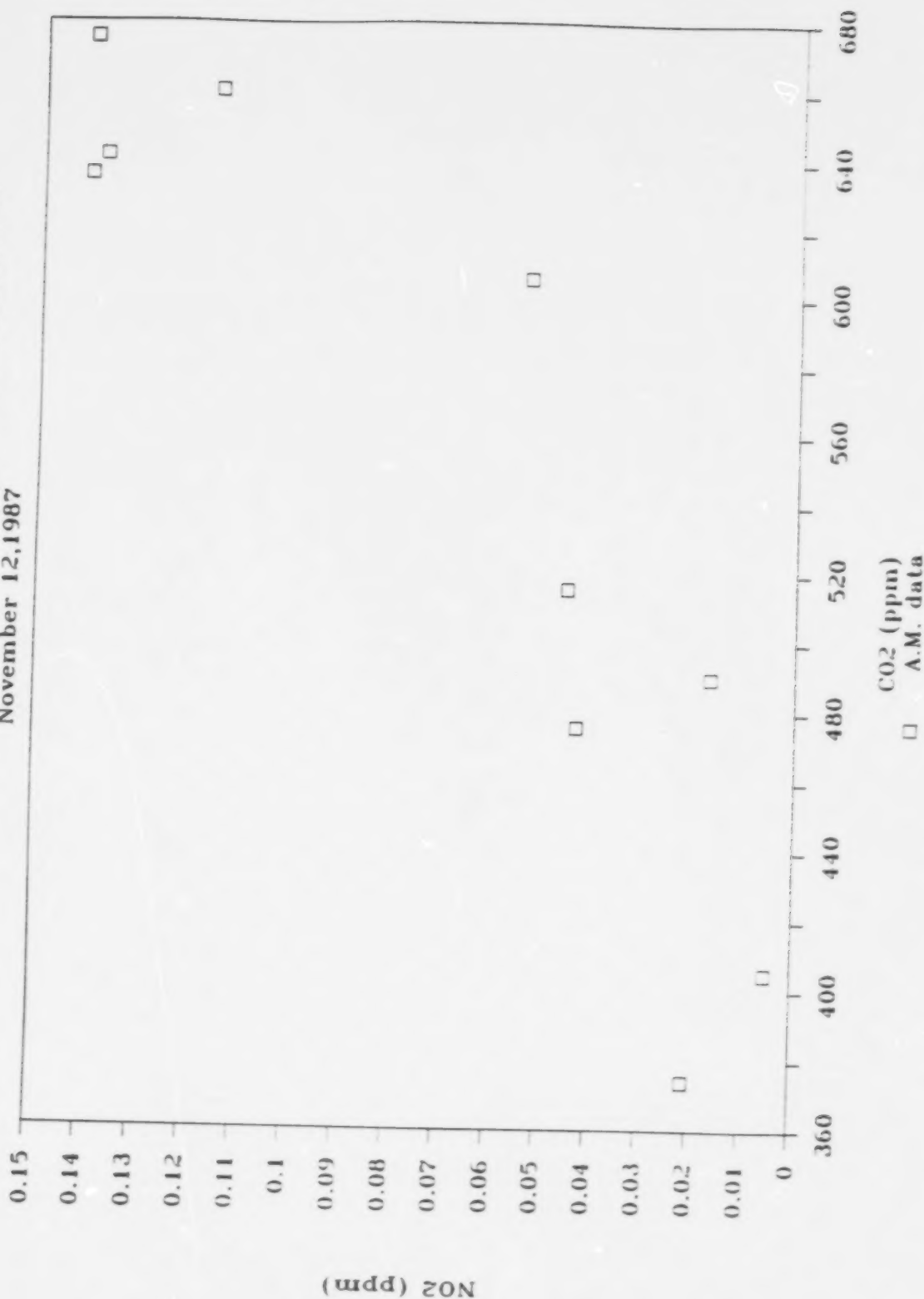
725 LEVEL AVG. EXH. CORRELATION

November 12, 1987



725 LEVEL CORR. AVG. EXH. CORRELATION

November 12, 1987

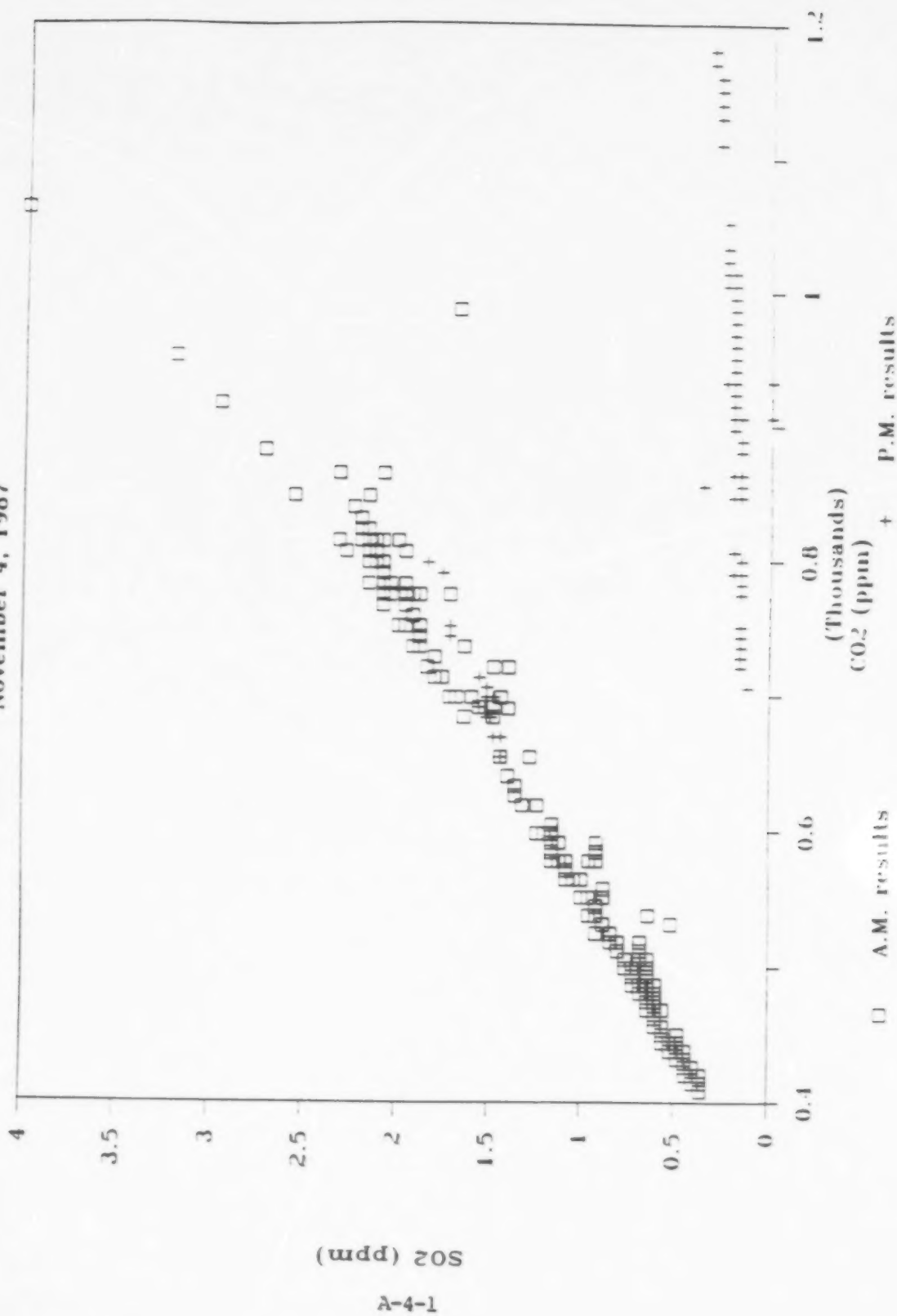


APPENDIX A-4

SO₂ vs CO₂

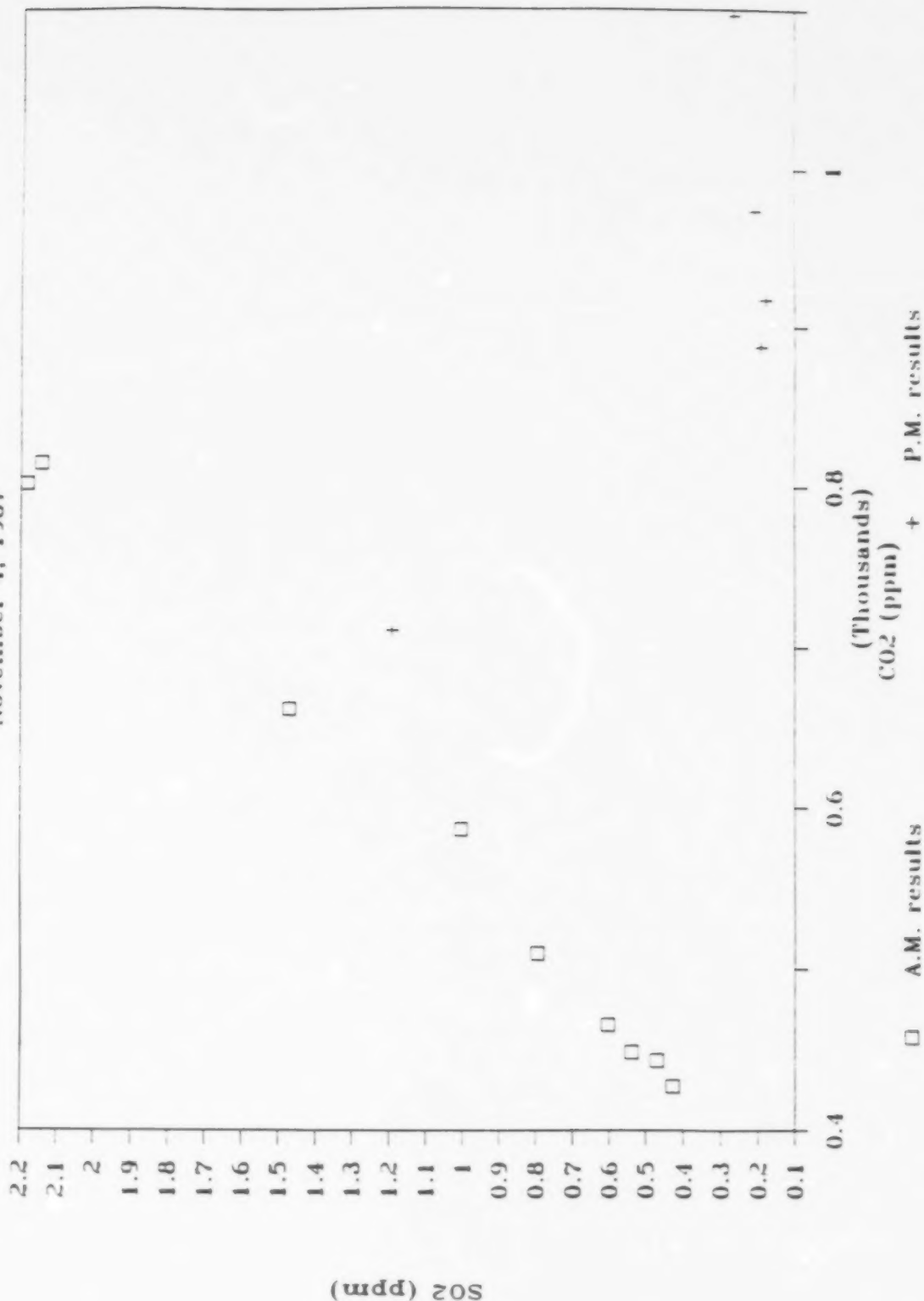
1000 LEVEL EXH. CORRELATION

November 4, 1987



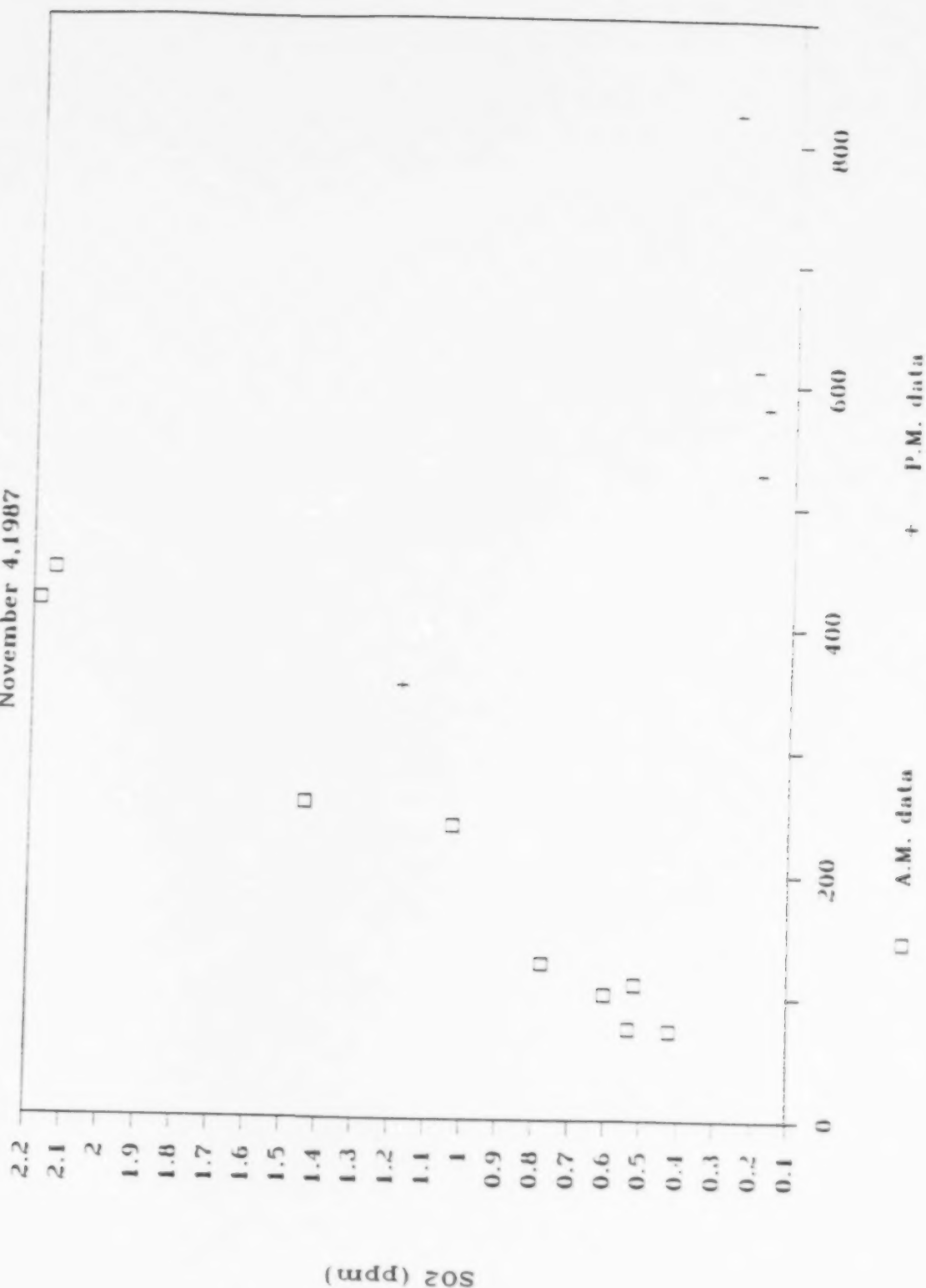
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



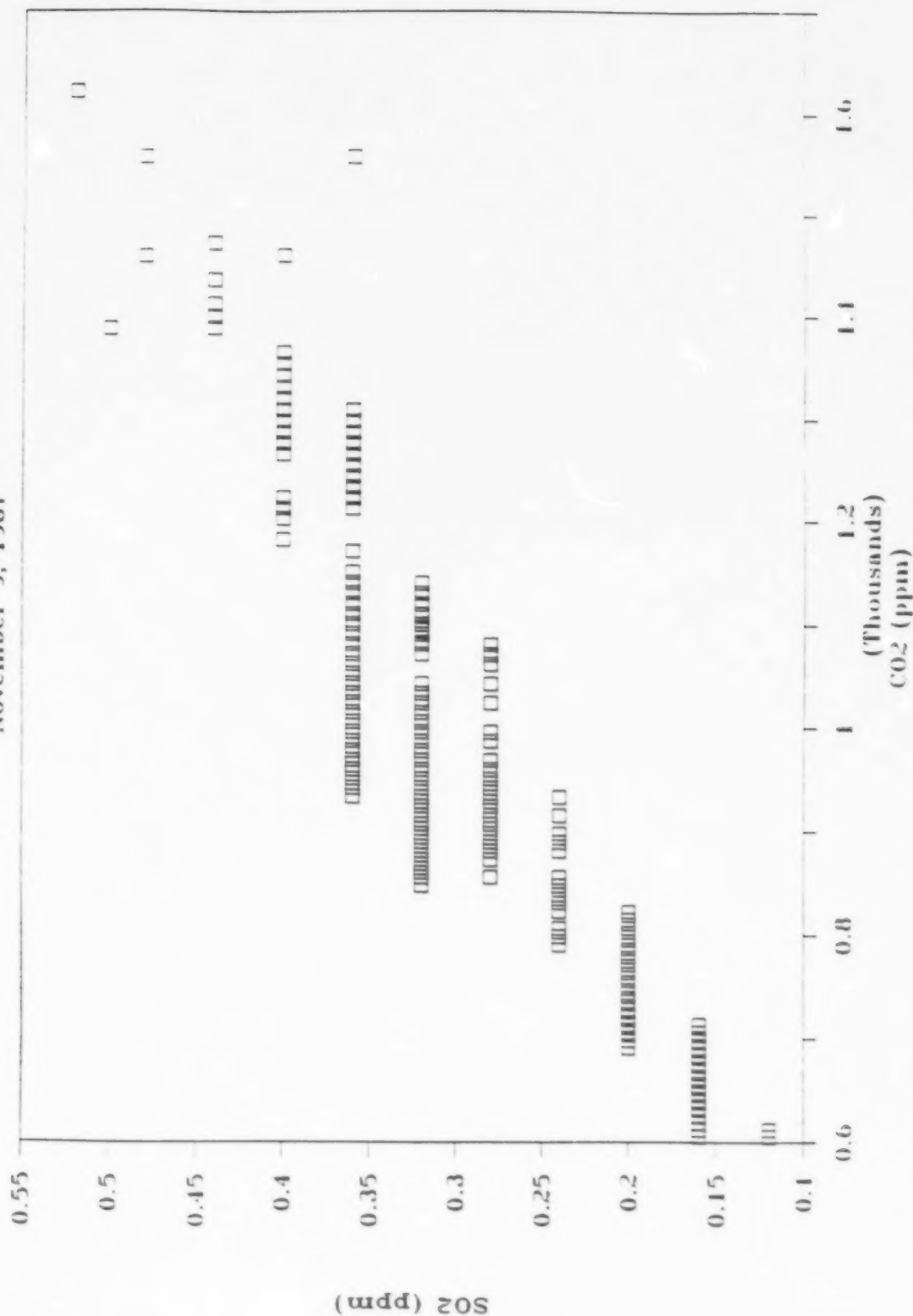
1000 LEVEL AVG. EXH. CORRELATION

November 4, 1987



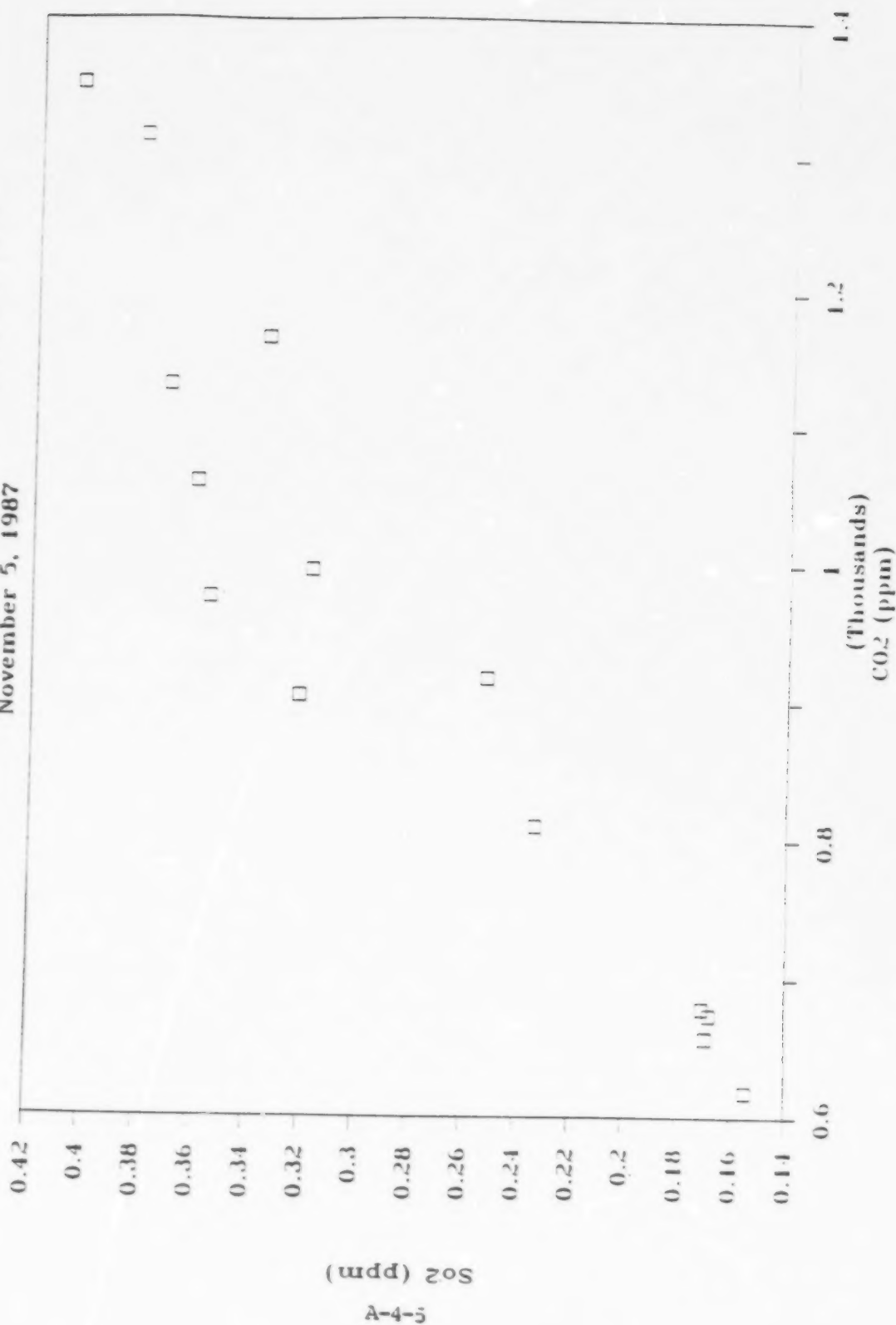
1000 LEVEL EXH. CORRELATION

November 5, 1987



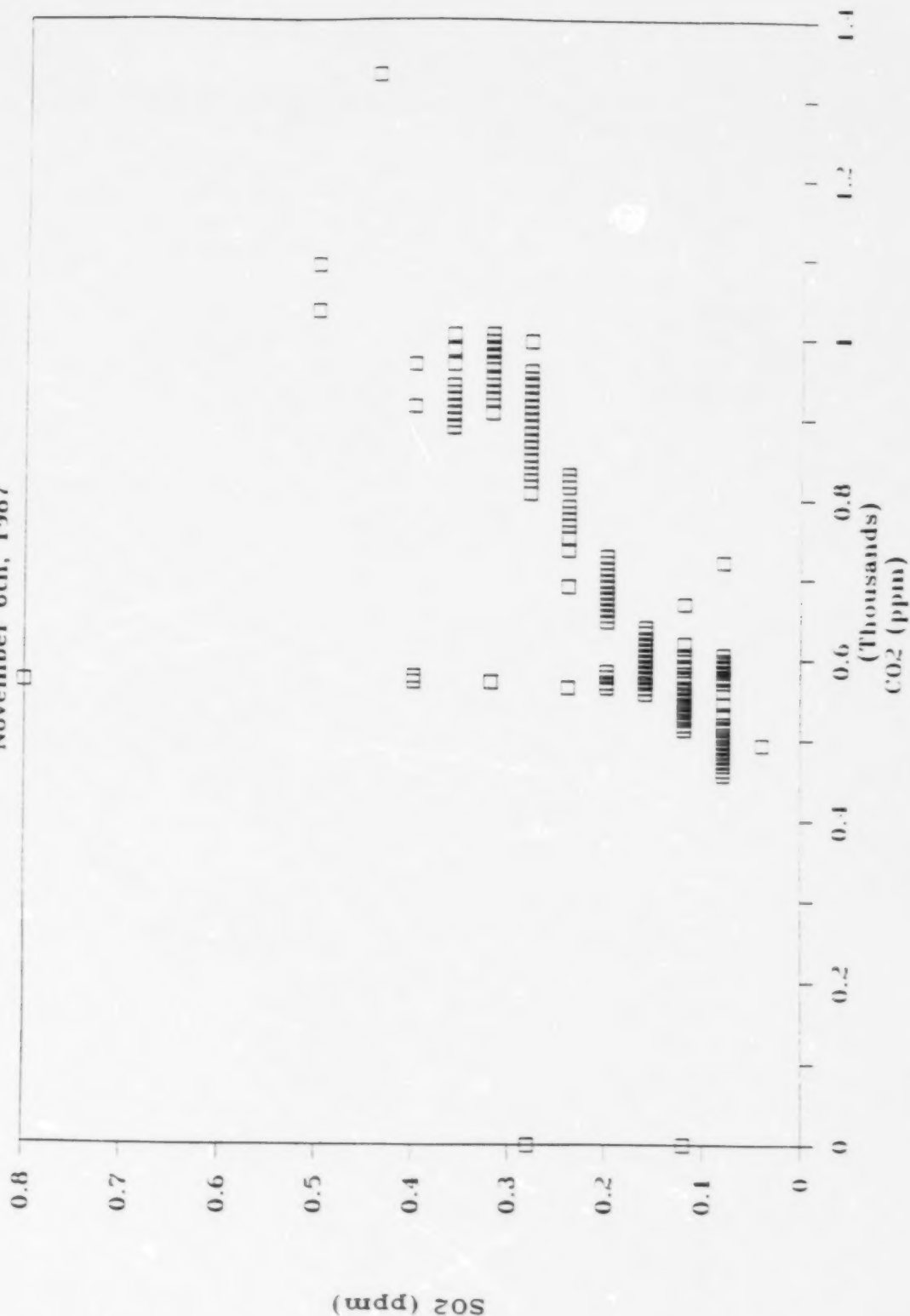
1000 LEVEL AVG. EXH. CORRELATION

November 5, 1987



1000 LEVEL EXH. CORRELATION

November 6th, 1987



1000 LEVEL AVG. EXH. CORRELATION

November 6th, 1987



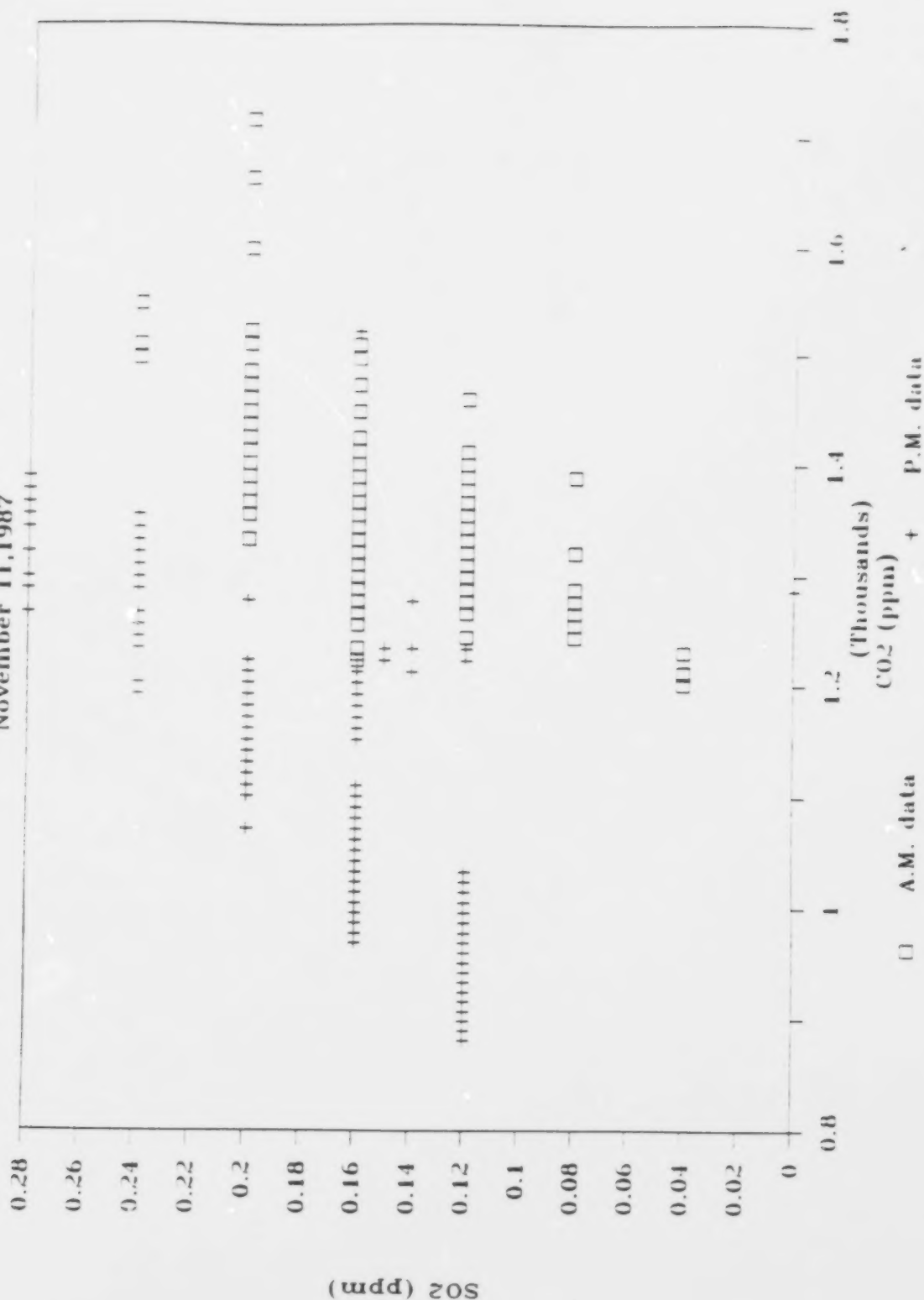
725 LEVEL AVG. EXH. CORRELATION

November 10, 1987



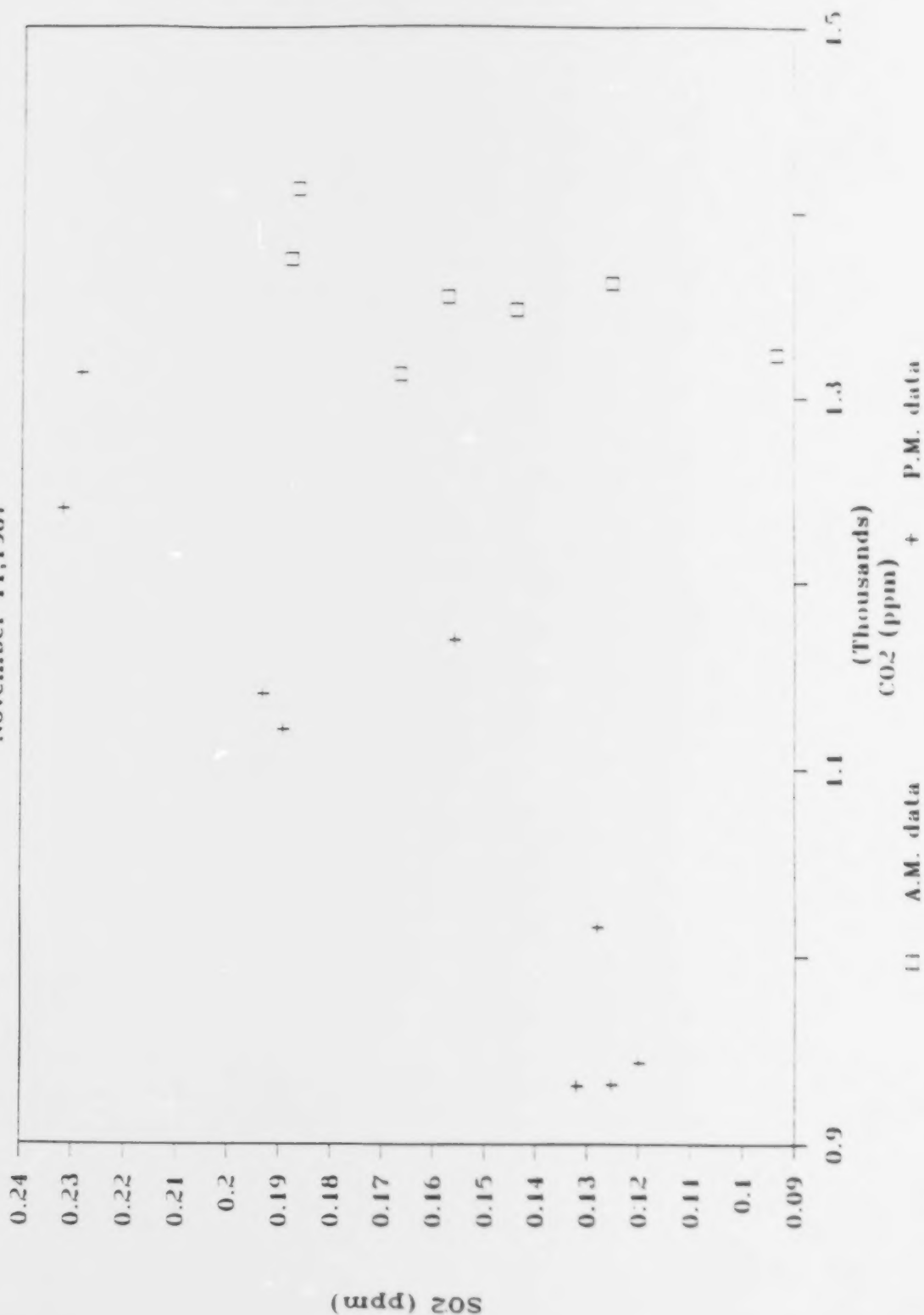
725 LEVEL EXH. CORRELATION

November 11, 1987



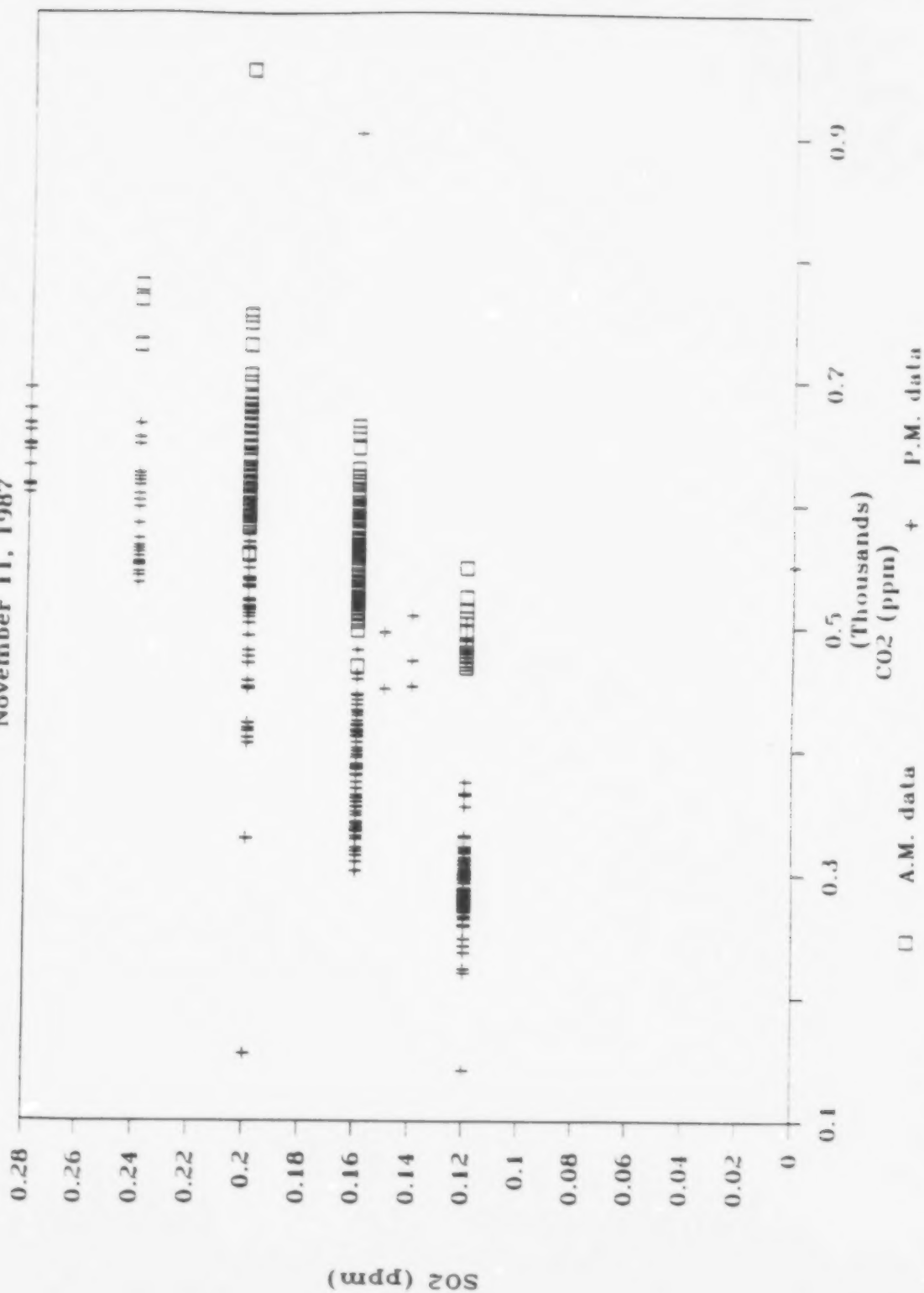
725 LEVEL AVG. EXH. CORRELATION

November 11, 1987



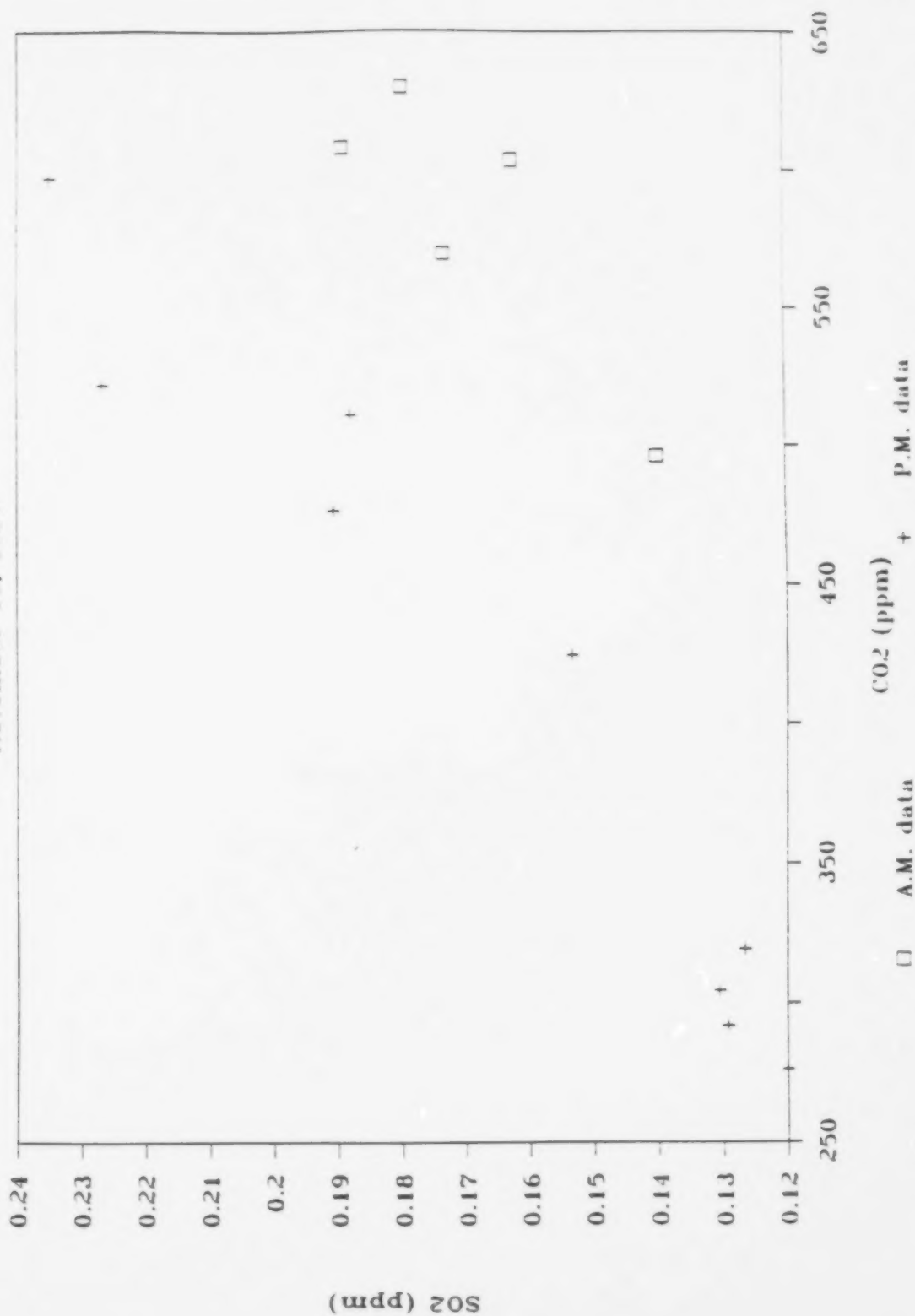
725 LEVEL CORR. EXH. CORRELATION

November 11, 1987



725 LEVEL CORR. AVG. EXH. CORRELATION

November 11, 1987



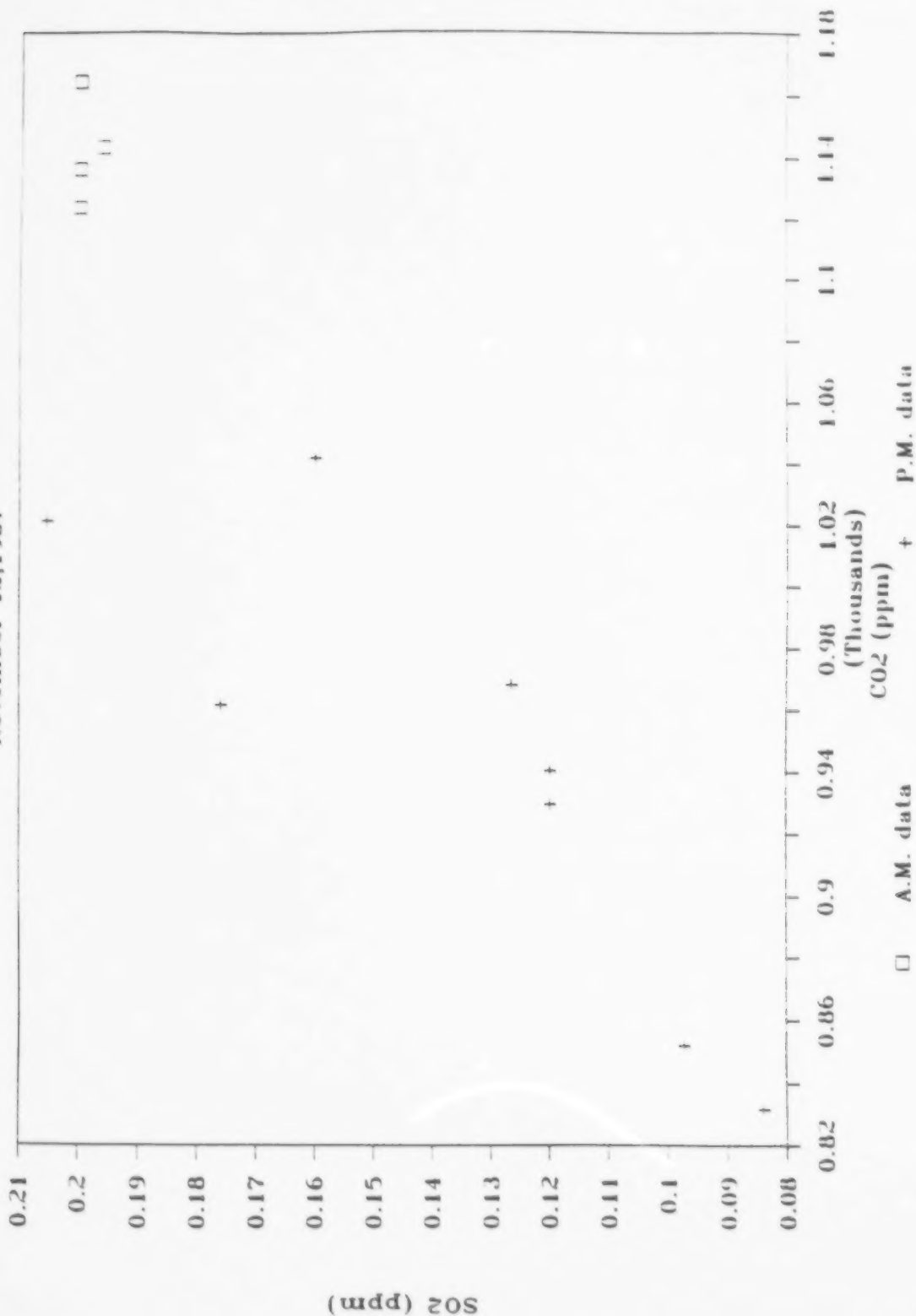
725 LEVEL EXH. CORRELATION

November 12, 1987



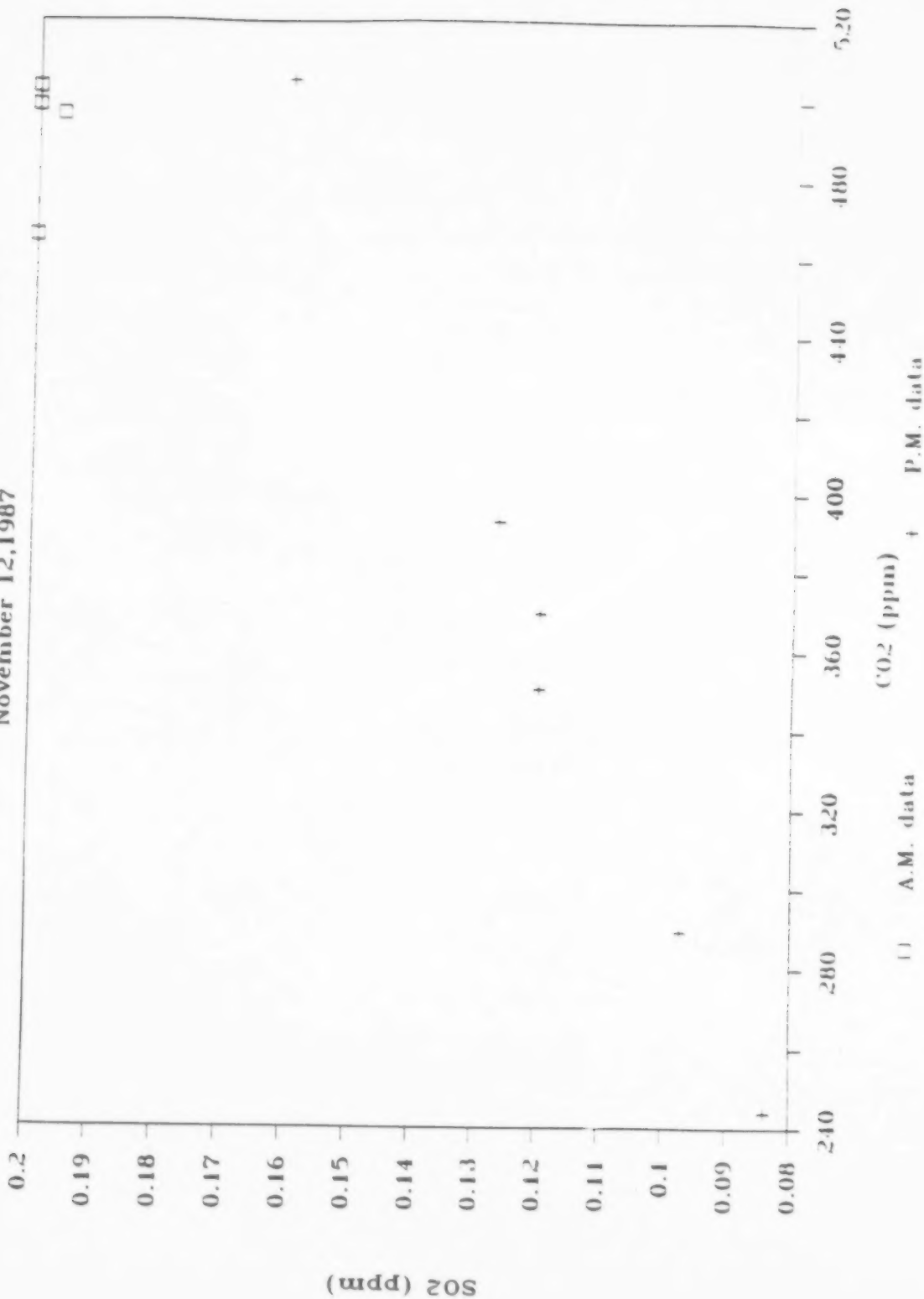
725 LEVEL AVG. EXH. CORRELATION

November 12, 1987



725 LEVEL CORR. AVG. EXH. CORRELATION

November 12, 1987



APPENDIX B

POWER LINE CARRIER SYSTEM INFORMATION

Appendix B: Power Line Carrier System Information

The PLC system is manufactured by:

Enercon Data Corporation
7464 W. 78th Street
Minneapolis, MN
55435 USA
Tel. (612)829-1900
Contact: David Bakke

It is distributed in Canada by:

Mechanical Equipment Services
1255A Reid Street, Unit 8
Richmond Hill, Ontario
L4B 1E9
Tel. (416)881-8900
Contact: Mike Tate

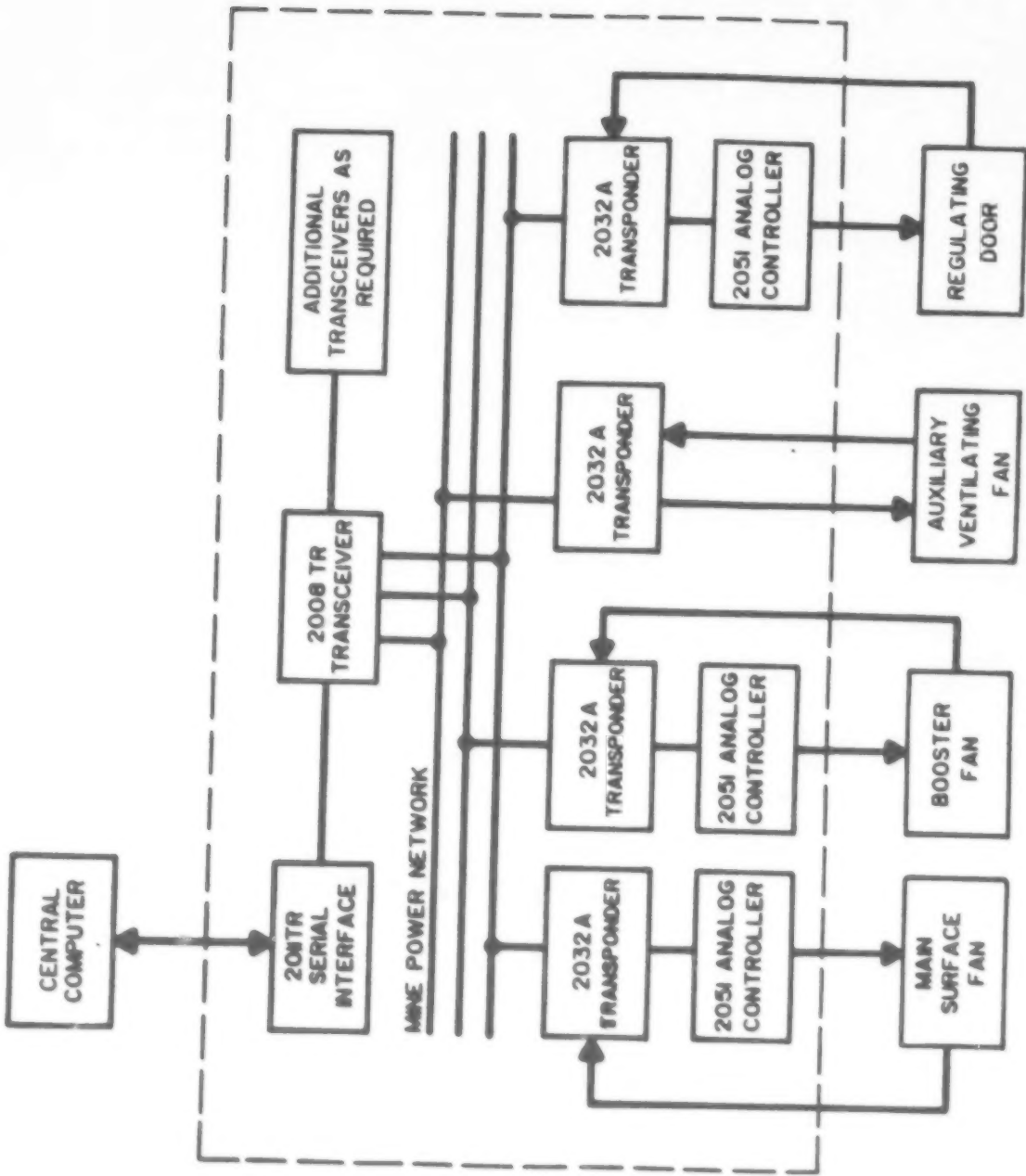
The following components have application in the ventilation control system:

- 2011TR** The 2011TR Serial Interface is an interface between an RS-232 port and the RS-422 port used by the 2008TR transceiver. It is used to communicate between a computer and the PLC system. Cost: \$ 770.
- 2008TR** The 2008TR Transceiver transmits and receives data from the power lines. Each 2008TR can communicate with up to 64 stations. Cost: \$ 770.
- 2032A** The 2032A Transponder is a two-way control station. The device provides two binary output controls suitable for on/off control. It also provides a binary input which could return the status (on or off) of the fan, and an optional seven bit analog input suitable for returning the control position of a fan or door. Enercon says that the 480 VAC model will work on the 575 volt underground power supply. Cost: \$ 522.

2051 The 2051 Analog Controller provides seven bits of output control data suitable for controlling a main surface fan, a booster fan, or a regulating door. The 2051 operates in conjunction with the 2032A. Cost: \$ 316.

Figure B.1 illustrates the PLC system in conjunction with the ventilation control system.

Figure B.1. Ventilation control using the PLC system.



APPENDIX C

CONTROLLER INFORMATION ON MAIN SURFACE FANS

Appendix C: Controller Information for Main Surface Fans

C.1 Variable Pitch-in-Motion Rotors

The V-5 and V-4 fans were made by:

TLT-Babcock, Inc.
3480 West Market Street
Akron, Ohio
44313 USA
Tel. (216)867-8540
Contact: George Gamble

For a variable pitch-in-motion rotor (to be attached to the existing motors) the company quoted a price of \$ 434 900 for aluminum blades, and \$ 455 700 for stainless steel blades. The cost was the same for both fans.

The V-3 and V-2 fans were made by Sheldons Engineering. This company is now represented by:

Unsmech Inc.
8530 Delmeade
Montreal, Quebec
H4T 1L6
Tel. (514)737-6869
Contact: Charles R. Unsworth

The company does not make variable pitch-in-motion blades of this size. However, for the purpose of comparison, the company quoted a price of \$ 139 760 for a replacement rotor for the V-3 fan, and \$ 106 926 for a replacement rotor for the V-2 fan. Even if variable pitch-in-motion rotors could be built, they would cost more than this.

C.2 Variable Speed Controllers

The V-5 and V-4 fans are powered by wound-rotor motors. The motors are 3000 hp, 2000 hp, and 1000 hp, respectively. These motors can be efficiently controlled by Slip Energy Recovery Drives, which return power to the line when used at slower speeds.

The V-2 and V-3 fans, powered by a squirrel-cage induction motor, would be controlled by changing the frequency of the AC power fed to the motor. This type of controller is slightly less efficient than the Slip Energy Recovery drives.

The following company was contacted to provide cost estimates for speed controllers for the main surface fans:

Relcon Inc.
2535 Boulevard Cavendish
Montreal, Quebec
H4B 2Y5
Tel. (514)487-6711
Contact: Michel Riverin

The following prices included controllers and excluded motor starters:

V-5: \$ 235 000
V-4: \$ 135 000
V-3: \$ 70 000
V-2: \$ 70 000

APPENDIX D

CONTROLLER INFORMATION ON BOOSTER FANS

Appendix D: Controller Information for Booster Fans

The principal supplier of underground fans for BMS-M is:

Alphair Ventilating Systems
118 Midland Street,
Winnipeg, Manitoba
R3E 2Y6
Tel. (204)775-8531
Contact: Dave Gardner

Table D.1 contains the cost information for variable pitch-in-motion fans, and the costs of equivalent normal fans.

Table D.1 Variable pitch-in-motion fans from Alphair.

Fan	Price	
	Normal	Controllable
36-17-1170 10 hp	\$ 3 230	\$ 8 130
36-17-1770 10 hp	2 590	7 490
36-17-1770 30 hp	3 640	8 540
36-17-3450 5 hp	2 400	7 300
38-21-1770 40 hp	4 870	9 770
38-21-1770 50 hp	5 085	10 085
42-26-1770 75 hp	7 345	12 245
45-26-1770 100 hp	8 565	13 465
45-26-1770 125 hp	10 130	15 030
48-26-1170 40 hp	7 555	12 455
48-26-1170 50 hp	7 755	12 655
48-26-1770 125 hp	10 485	15 385
60-26-1170 60 hp	8 650	13 550
60-26-1170 125 hp	12 930	17 830
72-26-1170 200 hp	18 945	23 845

Table D.2 lists the booster fans at BMS-M, excluding fans about to be removed, and including fans about to be installed. The table indicates the controllable replacement, and the cost of replacement.

Table D.2 Controllable replacements for booster fans.

Level	Current Fan	Controllable Fan	Price
50	60" x 60hp	60-26-1170	\$ 13 550
100	19" x 7hp	36-17-1170	8 130
150	19" x 7hp	36-17-1170	8 130
200	19" x 7hp	36-17-1170	8 130
250	19" x 7hp	36-17-1170	8 130
375	38" x 40hp	38-21-1770	9 770
375	48" x 40hp	48-26-1170	12 455
375	48" x 35hp	48-26-1170	12 455
475	60" x 60hp	60-26-1170	13 550
575	38" x 40hp	38-21-1770	9 770
575	48" x 40hp	48-26-1170	12 455
575	48" x 40hp	48-26-1170	12 455
575	72" x 200hp	72-26-1170	23 845
725 (6 sub)	29" x 30hp	36-17-1770	8 540
725 (5 sub)	38" x 40hp	38-21-1770	9 770
725 (1 sub)	36" x 75hp	42-26-1770	12 245
725 (sill)	78" x 150hp	72-26-1170	23 845
725 (sill)	60" x 125hp	60-26-1170	17 830
850	Dust 100hp	45-26-1770	13 465
900	24" x 25hp	36-17-1770	8 540
1000	45" x 125hp	45-26-1770	15 030
1000	45" x 125hp	45-26-1770	15 030
1200	38" x 40hp	38-21-1770	9 770
1200	38" x 40hp	38-21-1770	9 770
1200	38" x 40hp	38-21-1770	9 770
1325	42" x 75hp	42-26-1770	12 245
1325	42" x 75hp	42-26-1770	12 245
TOTAL COST			330 920

There is one other booster fan: the V-6 exhaust fan. This fan is 400 horsepower, and Alphair doesn't sell variable pitch-in-motion fans of this size. To control this fan, a variable speed controller would be used, such as the one used for the V-2 fan (see Appendix B). This controller costs \$ 70 000, bringing the total cost of controllable booster fans to \$ 400 920.

Variable speed control is not practical for the other booster fans, because the controllers are very bulky and more costly. The cost of 200, 100, and 50 horsepower controllers is \$ 37 000, \$ 26 000, and \$ 16 000, respectively.

APPENDIX E

INFORMATION ON CONTROLLABLE REGULATING DOORS

Appendix E: Information on Controllable Regulating Doors

The following company provided the information on their controllable doors:

M & I Door Systems Ltd.
230 Bayview Drive, Units 5 - 7
Barrie, Ontario
L4N 5E9
Tel. (705)722-7800
Contact: Ray Anne Taylor

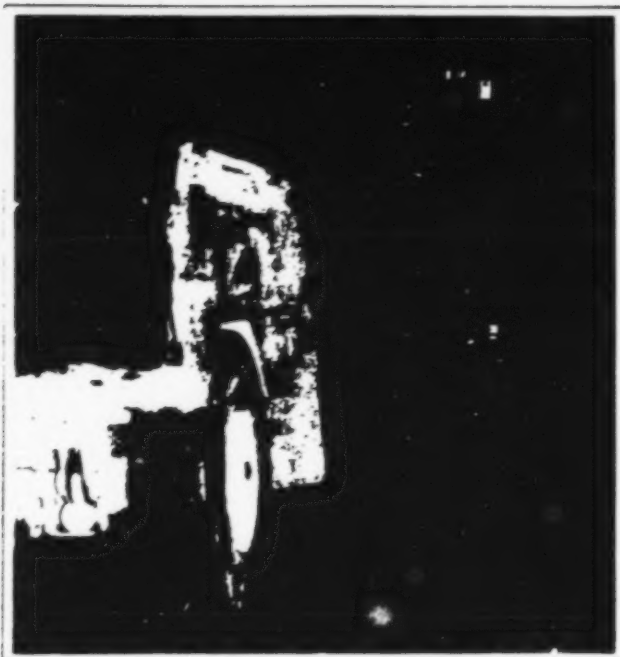
M & I suggested their High-pressure Steel Sectional door. The doors can support static pressure of up to 20" wg. Less expensive models come for 6" wg and 14" wg. The prices range from \$ 10 562 for a 8' x 10' door at 6" wg, to \$ 11 809 for a 13' x 10' door at 14" wg. For cost calculations, it is assumed that all doors are 13' x 10' at 6" wg.

The doors are easily controlled, and come equipped with the required limit switches. They have been installed successfully in mines.

COPPER CLIFF DOOR Manufacturing (1980) Ltd.

MANUFACTURERS OF DOOR SYSTEMS FOR MINING & INDUSTRY

POSI-DRIVE.



We are pleased to announce that after several years of research and development, Copper Cliff Door Manufacturing (1980) Ltd. has introduced an advanced design of the popular **Re-Coil-Away** rubber door system.

The newly-designed **Posi-Drive** model enhances the use of **Re-Coil-Away** in underground applications through the use of a unique positive downward-drive action which ensures ease of closing at pressure

differentials ranging as high as 3.5" W/G.

Utilizing an endless roller chain mechanism housed completely within the guide assemblies, the rubber door curtain is mechanically lowered to a fully-closed position by the steel bottom bar attached to the base of the curtain, thus ensuring a proper seal during each cycle.

For surface applications, **Posi-Drive** overcomes closing problems

due to extremely heavy windloading and/or negative pressure situations prevalent in some large plant operations.

In areas where door speed (over 18" per second) is of extreme importance, **Posi-Drive** assures trouble-free operation with no concerns regarding jamming, etc., at maximum speeds of two (2) feet per second.

[illegible]

DISTRIBUTOR:

RESEARCH (1990) 1990
 Advances in Nursing, 1 (1990) 1-11

WILLIAM J. CUNNINGHAM
101-91-511647 PARTIAL PRIVACY

[illegible]

COPPER CLIFF DOOR Manufacturing (1980) Ltd.

MANUFACTURERS OF DOOR SYSTEMS FOR MINING & INDUSTRY

HI-PRESSURE STEEL SECTIONAL DOOR SYSTEM

The Hi-Pressure Steel Sectional Door is designed expressly for use in underground areas where pressure differentials exceed the operating capabilities of the Posi-

Drive Door System, being 3.5" W/G. Constructed of extremely heavy-duty steel components, this door system is available in two pressure differential ranges: (i) to 6" W/G;

and (ii) to 12" W/G. In addition, the all-steel construction makes the Hi-Pressure Door ideal for use in areas where fire-resistancy is of prime concern.

TECHNICAL SPECIFICATIONS

DOOR PANELS

Shall be constructed of 16 ga. roll-formed, galvanized sheet metal. Vertical end supports to be constructed of 5" X 2" X .188" H.S.S. tubing with vertical intermediate supports constructed of 3" X 2" X .125" H.S.S. tubing. Maximum spacing of vertical supports not to exceed 24" centre to centre.

Horizontal supports shall consist of two 2" X 2" X 3/16" angles welded back to back to form a rigid "T" formation, then secured to each vertical support to provide minimum deflection of door panels at pressure differentials up to 12" W/G.

ROLLER TRACK

Shall be constructed of roll-formed, galvanized steel with a minimum thickness of .1090". Vertical roller track shall be mounted on an 8" X 2 1/4" structural channel and horizontal roller track mounted on 4" X 1 1/4" structural channel for maximum support strength and ease of installation.

HARDWARE

Both intermediate and end hinges shall be constructed of 1/4" thick, hot-rolled mild steel complete with solid 3/16" hinge pin. Roller shall be composed of solid steel 3" O.D. X 5/8" thickness, complete with 3/4" O.D. shaft and sealed 1" roller bearing for trouble-free operation. Roller brackets and supports shall

be constructed of hot-rolled steel with a minimum thickness of 1/4". All hardware to be secured by 3/8" Grade 5 nuts and bolts throughout.

TORSION COUNTERBALANCE SPRING

Oil-tempered helical torsion spring assemblies shall be mounted on 1 1/4" O.D. stressproof steel shafts and shall have a minimum life of 50,000 cycles. Lifting cables shall be of 1/4" O.D. stainless steel aircraft cable for extra strength and safety.

OVERHEAD TROLLEY ASSEMBLY

Shall be constructed of 2" X 2" structural angle with a minimum thickness of .188". Trolley chain shall be #50 ANSI roller chain utilizing #50 sprockets throughout. Trolley lifting arm shall be composed of 1" X 1/4" steel complete with quick-disconnect to allow door assembly to be raised or lowered manually should electrical mechanism be inoperative.

ELECTRIC OPERATOR

Electrically-operated doors shall be equipped with a compact electric operator to CSA standards.

Motor to be high-starting torque, trolley-type, having sufficient power to open and close door at an approximate speed of 8" to 10" per second through a gear reducer drive mechanism connected to trolley

assembly with #50 ANSI roller chain. Operator shall be equipped with rotary screw-type limit switches to control open and close door positions and a solenoid-operated brake system to stop and hold door in any position. All electrical components meet EEMAC 1 Standards, unless otherwise specified.

CONTROL PANEL

Wall-mounted control panel is 20" X 24" X 6 1/2" CSA approved EEMAC 12 enclosure. Components consist of Allen Bradley Type 705 fused disconnect, Size "O" reversing starter with three motor overload protection coils, electrically and mechanically interlocked, and open, close and stop buttons mounted on panel cover. Control circuit is 120 VAC. Two Crouse Hinds, Model AFC 210, pullcords are provided with each door, however alternate types of control stations are available at customer's request.

BOTTOM SAFETY EDGE

A 24V electrically-controlled flexible emergency door-stopping device comprised of two aluminum foil contact strips mounted on a live foam rubber base is provided with each door. These components are enclosed in a weatherproof, electrically heat-sealed, vinyl-coated nylon covering which also serves as a sealing device between the base of the door and the floor or sill.

C

[illegible]

APPENDIX F

AIRFLOW SENSORS INFORMATION

APPENDIX F

AIR FLOW SENSORS INFORMATION

There are three types of flow sensors available:

- a) Vortex shedding
- b) Pitot tube
- c) Anemometer

For underground use, Vortex shedding and Anemometer sensors were considered (Pilot tubes are not economical if used as a single point). The cost of most sensors are all in the range of \$3000-\$3500.

1. **J-Tec Sensor (Vortex shedding)**

Distributor: Cromatic
989 Elisabetha Rd.
Sudbury, Ontario
P3A 5K2
Att: M.J. Gribbons
Tel: (705) 560-3549

2. **Montan-Forschung (Anemometer)**

Hofstrasse 56-60
D-4010 Hilden
W. Germany
(02103) 6822
FAX: (02103) 21797

3. **Sieger (Vortex shedding)**

Price: ~\$5,500.

Distributor: Safety Supply
8210 Route Transcanadienne
St-Laurent, Quebec
H4S 1S2
(514) 332-6100
Att: sophie Brouillard

For the main shafts, both Vortex shedding systems and Pitot tube arrays can be used. Vortex shedding is preferable because of the greater accuracy and smaller dirt sensitivity.

1. **Kurz Eva 4000 (Vortex shedding)**

Distributor: Safety Supply
8210 Route Transcanadienne
St-Laurent, Quebec
(514) 332-6100

Cost for 12' diameter shaft system: \$25-30,000
(includes 10 sensors)



J-TEC ASSOCIATES, INC.

JPS

VA216B AIRFLOW SENSOR

GENERAL DESCRIPTION

The VA216B Airflow Sensors are designed to continuously monitor air flow in a ventilation shaft or hazardous mining area. The VA216B has no moving parts, long-term stability and a broad operating range. J-TEC's principle of operation is measuring air movement by the rate of vortex formation in the wake of a vortex generating rod. The frequency at which vortices are shed is in direct proportion to the air velocity. Transducers are placed on each side of the vortex path. One transducer transmits while the other receives. Vortices passing through the ultrasonic beam are detected and processed through the sensor electronics. Hundreds of J-TEC Airflow Sensors have been installed in working mines with excellent performance and long-term reliability.

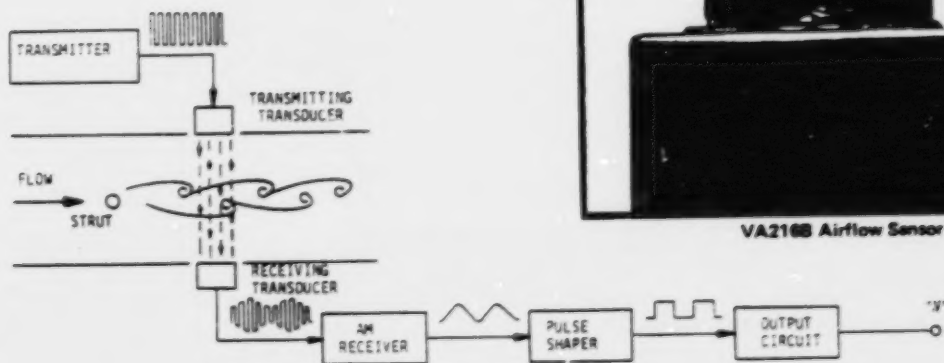
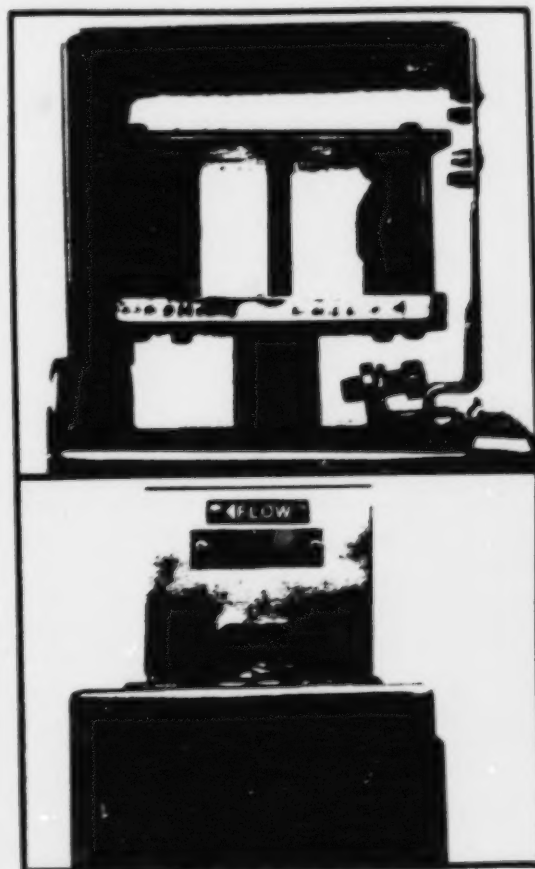


DIAGRAM OF FLOW SENSOR

The J-TEC VA216B is available in two ranges: 50 - 3000 feet per minute and 150 - 10,000 feet per minute. Standard outputs are 0 - 5 VDC with optional 4-20 ma. Because of the technique J-TEC uses in measuring air flow, your power required to operate the VA216B is a maximum of 35 ma. For proper operation, the load resistance should be 10,000 ohms or higher. Another feature J-TEC has added to the VA216B allows the customer to incorporate their own systems interfacing card inside the sensor enclosure. This allows flexibility with many computer based systems. There is no need for extra enclosures for their electronics, saving both equipment costs and installation time.

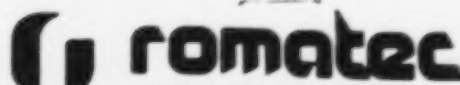


VA216B Airflow Sensor

ADVANTAGES

- Continuous Monitoring for Hard Copy Readout
- Incorporation into any Computer Based System
- No Moving Parts to Wear Out by Harsh Environments
- Self-contained Sensor Package
- Intrinsically Safe
- Fast Response to Changing Conditions

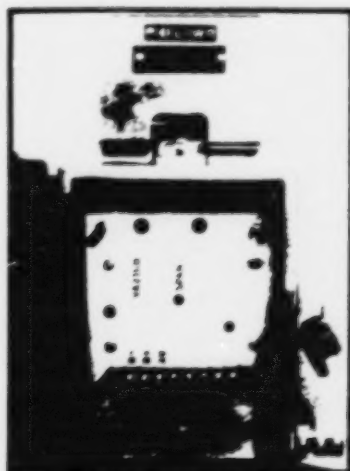
MICHAEL J. GRIBBONS, B.A.Sc.
Branch Manager



VALVES - PUMPS - INSTRUMENTS

989 ELISABELLA STREET
SUDBURY, ONTARIO P3A 5K2

Tel: (705) 560-3548 (416) 499-0222
Fax: (705) 560-1076



VA216B Electronics

CALIBRATION

In most installations, the VA216B is fastened to a wall or overhead. The air velocity at the VA216B mounting location is typically different than the air velocity at the floor or center of the passageway. For this reason, it is necessary to make a number of air flow measurements and determine the average air velocity through the passageway. The Span Control may be adjusted to cause the analog output of the VA216B to be equal to the average flow. The Span Control is screwdriver adjusted and is located on the panel which is exposed when the access lid is raised.

This procedure is to be done upon initial installation, whenever air flow is altered by adding or closing passageways, and initially at six-week intervals. It is recommended that the user create a calibration log showing the amount of adjustment necessary at each calibration. After a calibration history has been established, the user may elect to modify the six-week interval. For stable situations, the calibration interval may be lengthened. However, if significant changes are required at each calibration, the interval should be shortened.

Calibration of the VA216B requires a precision hand-held air flow meter and a voltmeter. Using the hand-held anemometer, measure the air flow at regular intervals horizontally and vertically from the floor to the ceiling to obtain the average air flow through the passage. Then adjust the span of the VA216B until the voltage is equal to the average velocity rate.

VA-216B AIRDRAFT SENSOR SPECS

Range: 50 - 3000 f.p.m.
150 - 10,000 f.p.m.
Power Input: 10 to 20 VDC at 35 ma maximum
Outputs: Standard 0-5 VDC
Optional 4-20 ma
Material: Stainless steel enclosure and sensor head
Repeatability: $\pm 1\%$ of point
Temperature: 0° C to +50°C
Dimensions: 12.5" x 7" x 4"
*Specify range with order.

M.S.H.A. CLASSIFIED

CLASS	ISSUE NO.
C	11
D	11
E	16
F	17
G	20
H	6
L	21

FOR MORE INFORMATION CONTACT:



romatec

989 ELISABELLA RD., SUDBURY, ON. P3A 5K2

TEL: (705) 560-3548

TELEX: 06-908756 • FAX: (705) 560-1076



J-TEC ASSOCIATES, INC.
317-7th Ave., S.E.
Cedar Rapids, Iowa 52401
(319) 366-7511

Continuous monitoring of mine air velocities with the intrinsically safe Remote Transmission Anemometer

Adjustable: 3 measuring ranges

0.3 - 3 m/s

0.3 - 6 m/s

0.3 - 12 m/s

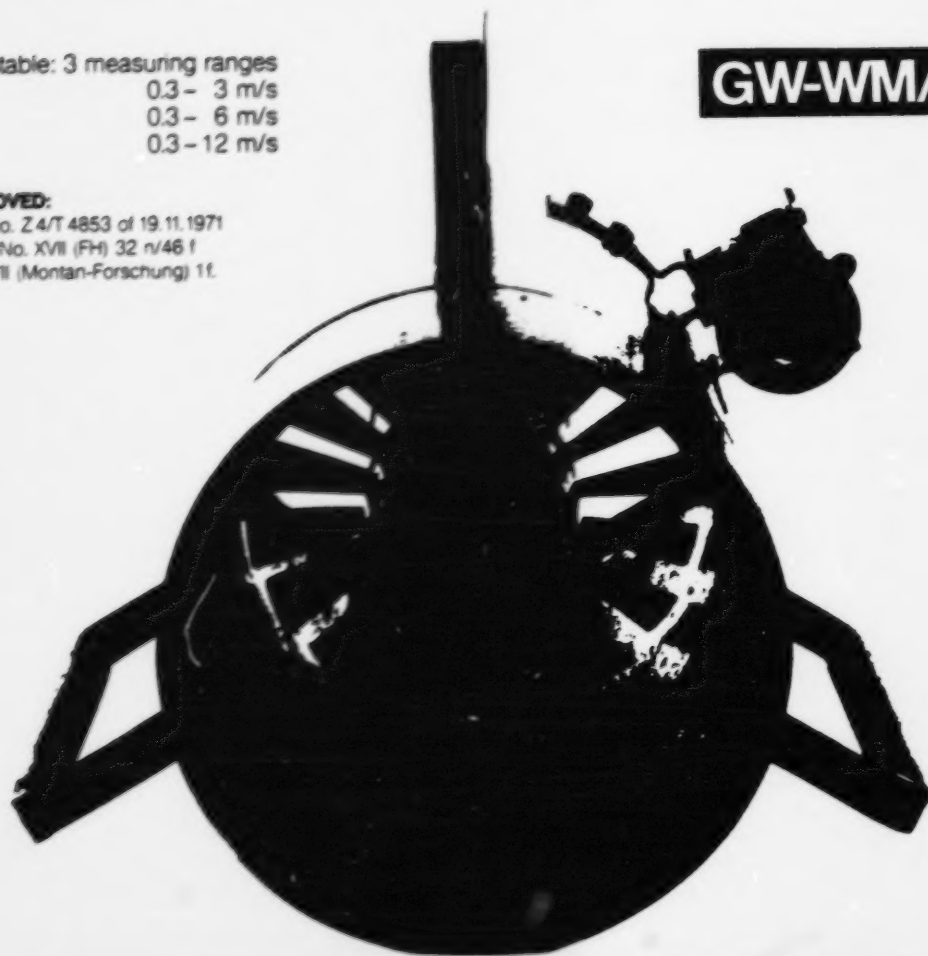
APPROVED:

BVS-No. Z 4/T 4853 of 19.11.1971

LOBA-No. XVII (FH) 32 n/46 f

No. XVII (Montan-Forschung) 1f.

GW-WM/4



CHUNG

...intrinsically safe - suitable for all transmission systems!

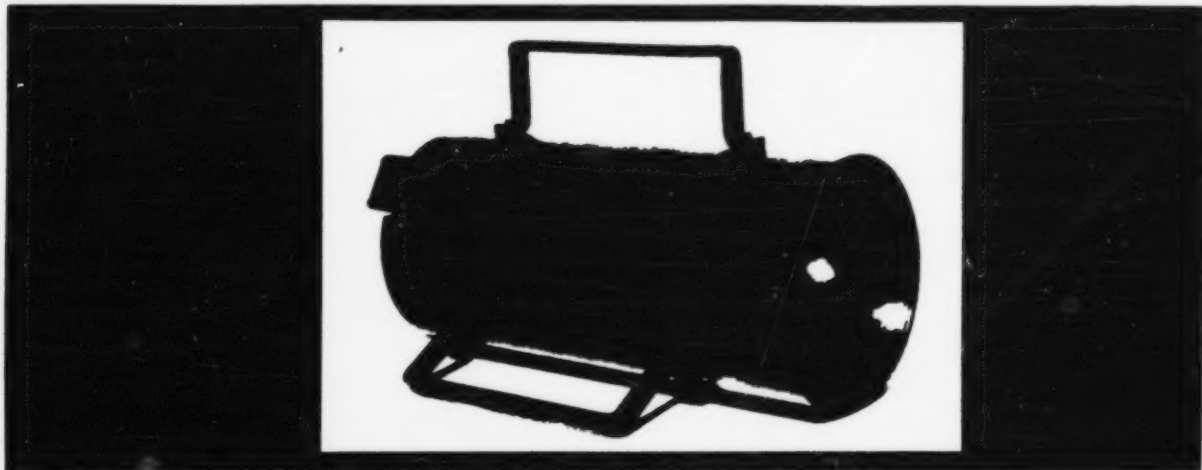
By means of the Remote Transmission Anemometer type GW-WM/4 it is possible to centrally register the mine air velocity continuously with the aid of electronic pulses. The unit operates with inductive frequency sensing. Every revolution of a fan wheel produces pulses that are subsequently amplified and then divided to give a norm 5-15 Hz output frequency for transmission. The open collector output can be directly connected to any of the standard remote transmission-systems which also feed the anemometer with the 12 volt DC and about 9 mA.

The signal is transmitted to the surface and there converted into a frequency proportional current. The current signal feeds a line- or dot-printer.

Measuring range

The anemometer is designed for mine air velocities between 0.3-3; 0.3-6; 0.3-12 m/sec.

The fan wheel is mounted in a cylindrical tube. By means of three strap handles mutually offset by 120° the unit can be placed in any position into a protection pipe with 300 mm inside diameter. The cable is stress-relieved with a trumpet-type junction.



Mechanical design

The electronics are accommodated in the hub of the anemometer in an airtight metal casing with a plug socket. This unit can be easily replaced at any time. The electrical connection is a standard three-core cable.

Technical data

Length	350 mm
diameter without handles	160 mm
required protection pipe diameter	300 mm
Supply voltage	12 VDC
current consumption	9 mA
sensing frequency output	5-15 Hz
Measurable mine air velocity range	0.3-3 m/s, 0.3-6 m/s, 0.3-12 m/s

Code No. 30060 Anemometer GW-WM/4 (complete)
Code No. 30070 Electronics VS-11/2



INTRINSICALLY SAFE ELECTRONICS FOR MINING

MONTAN-FORSCHUNG

F-6

DR. HANS ZILLER

IN CANADA/USA



KURZ
INSTRUMENTS INC.

E-7

SENSOR TYPE

Kurz "DynaPac" sensor is a pressure compensating sensor.

SENSOR CONSTRUCTION

Platinum wound ceramic sensor element.

PROBE PROTECTIVE WINDOW SUPPORTING PIPE

NIPPLES DESIGNATION K-SAF-12

PROBE PROTECTIVE WINDOW DIAMETER 0.75"

PROBE PROTECTIVE WINDOW CONSTRUCTION

6061-T6 Aluminum

REPEATABILITY $\pm 0.25\%$

CALIBRATION

Each sensor individually calibrated in NBS Traceable wind tunnel at the factory. Recommended optional Multipoint Velocity Profiler allows verification of function and calibration for each sensor individually.

VELOCITY RESPONSE TIME

Individual sensors 100ms; Overall systems 1 second.

VELOCITY RANGES

Velocity Ranges must be customer specified in increments of:

0-300 SCFM/RP 0-4,000 SCFM/RP

0-500 SCFM/RP 0-6,000 SCFM/RP

0-1,000 SCFM/RP 0-12,000 SCFM/RP

0-2,000 SCFM/RP

POWER REQUIREMENT PER SENSOR Up to 300 mA

ALLOWABLE OPERATING ENVIRONMENTAL

TEMPERATURE, SENSORS -25° to 125°C

ALLOWABLE OPERATING ENVIRONMENTAL

TEMPERATURE, PROBE MOUNTED TRANSMITTER

& SYSTEM ELECTRONICS ENCLOSURES 0 to 50°C

MAXIMUM PROBE LENGTHS (2 SENSORS)

Maximum probe length of 60' for -TAGE configurations (single-ended), and 90' for -TAGE configurations (double-ended).

PROBE TRANSMITTER JUNCTION BOX

NEMA Type 6"Wx4"Hx4"D. Includes barrier screw terminal strip for field wiring.

HOOKUP CABLE LENGTH, PROBE JUNCTION BOX TO ELECTRONICS ENCLOSURE

Any length of two-wire cable may be used as long as the voltage drop from the electronics enclosure to the probe is less than 4 Vdc.

System Electronics, DC Powered

MODEL 193DC LINEAR DC-POWERED ELECTRONICS MODULE

Linear 0-5Vdc Output. Includes signal

quires +15Vdc power supply. Senses

300 milliamperes per sensor.

over two-wire hookup to

sure, 8"x8"x4" with mounting

Model 193DC, For Systems

IMPORTANT NOTICE

Specifications are subject to change without notice. Kurz Instruments reserves the right to make engineering changes and product improvements at any time and without prior notice. Consult your local Kurz Representative or a Factory Application Engineer for information regarding current specifications.

System Electronics, AC Powered

MODEL 193AC AC-POWERED NON-LINEAR OUTPUT ELECTRONIC MODULE

A complete package including a 2.4 ampere power supply, and a current sense resistor is supplied to provide a non-linear voltage output signal. Painted steel fan-cooled enclosure. 14"x12"x8" with mounting flanges.

Model 193AC-8, For Systems Up To 8 Sensors

Model 193AC-16, For Systems Up To 16 Sensors

(uses 4.8 ampere power supply)

MODEL 193L-AC AC-POWERED LINEAR OUTPUT ELECTRONIC MODULE

A complete package including a 2.4 ampere power supply and signal conditioning board to provide a linear 0-5Vdc output signal. Painted steel fan-cooled enclosure. 14"x12"x8" with mounting flanges.

Model 193L-AC-8, For Systems Up To 8 Sensors

Model 193L-AC-16, For Systems Up To 16 Sensors

(uses 4.8 ampere power supply)

Options for EVA 4100 Systems

DESCRIPTION

Velocity Profiler

MODEL NO.
-142

Allows individual readings of EVA 4100 sensors.

Panel mounted inside electronics enclosure.

Includes multi-position switch and female banana

output jacks. Adjustable for AC and DC units.

Highly Recommended

Velocity Profiler with Digital Display

-14

Same as above with digital display

Digital Display, AC Linear Only

-D

Operation of Model 193AC at 220Vac/60Hz

-X

4-20 mA Isolated Output Signal

-13

Temperature Output Signal Conditioner

-18

Duct Air Flow Totalizer, 6 digit, non-resettable

-10

Duct Air Flow Totalizer, 6 digit, resettable

-10R

Dual Alarm, Setpoints For High & Low Duct

-11

Air Flow.



For applications in hostile industrial environments, use our EVA 4100 systems with their rugged 316 Stainless Steel clad sensors.

SPECIFICATION RELEASE-1/86

KURZ
INSTRUMENTS, INC.

CALL A KURZ APPLICATION ENGINEER FOR IMMEDIATE SERVICE

EVA 4100-4 AIRFLO
MAINTENANCE (1-800-434-7366)

F-8

© 1986 KURZ INSTRUMENTS, INC.
3071 GARDEN ROAD
MONTREY, CA 95040
(408) 545-0001
VIA TELETYPE 172170

APPENDIX G

BMS-M COMPUTERIZED VENTILATION NETWORK

PRESSURE (PSI)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
3290.	.00	.0
3260.	318.00	381.6
3240.	373.00	447.6
3040.	425.00	510.0
2740.	458.00	549.6
2490.	481.00	577.2
1990.	528.00	633.6
1490.	571.00	685.2
995.	613.00	735.6
0.	661.00	793.2

FAN NO. 3 HAS THE FOLLOWING 5 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PSI)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
1595.	.00	.0
1570.	278.00	333.6
1245.	311.00	373.2
870.	335.00	402.0
0.	349.00	418.8

FAN NO. 4 HAS THE FOLLOWING 7 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PSI)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
1270.	.00	.0
1245.	165.00	198.0
995.	193.00	231.6
745.	208.00	249.6
500.	229.00	274.8
250.	241.00	289.2
0.	259.00	310.8

FAN NO. 5 HAS THE FOLLOWING 10 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PSI)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
1940.	.00	.0
1870.	19.30	23.2
1740.	22.70	27.2
1500.	26.90	32.3
1245.	30.20	36.2
1050.	32.10	38.5
1000.	57.60	69.1
747.	67.00	80.4
374.	74.60	89.5
0.	70.30	94.0

FAN NO. 6 HAS THE FOLLOWING 7 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

DRY AIR MASSFLOW
(KG/S)

QUANTITY
(M3/S)

PRESSURE
(PA)

1520.	.00	.0
1495.	51.90	62.3
1245.	61.40	73.7
995.	67.50	81.0
745.	73.20	87.8
500.	76.90	92.3
0.	77.90	93.5

FAN NO. 7 HAS THE FOLLOWING 8 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
------------------	--------------------	----------------------------

2915.	.00	.0
2890.	51.40	61.7
2640.	56.60	67.9
2290.	61.40	73.7
1895.	66.10	79.3
1245.	71.70	86.0
500.	77.40	92.9
0.	81.20	97.4

FAN NO. 8 HAS THE FOLLOWING 8 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
------------------	--------------------	----------------------------

2990.	.00	.0
2965.	38.70	46.4
2815.	47.20	56.6
2565.	54.30	65.2
2215.	61.40	73.7
1595.	70.80	85.0
770.	80.20	96.2
0.	85.00	102.0

FAN NO. 9 HAS THE FOLLOWING 9 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
------------------	--------------------	----------------------------

2366.	.00	.0
2341.	28.40	34.1
2242.	33.00	39.6
1993.	38.70	46.4
1744.	41.50	49.8
1245.	45.30	54.4
498.	49.60	59.5
249.	50.00	60.0
0.	50.50	60.6

FAN NO. 10 HAS THE FOLLOWING 6 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
------------------	--------------------	----------------------------

(PA)	(M3/S)	(KG/S)
1045.	.00	.0
1020.	20.30	24.4
845.	23.60	28.3
500.	27.40	32.9
250.	29.70	35.6
0.	31.10	37.3

FAN NO. 11 HAS THE FOLLOWING 7 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
665.	.00	.0
660.	13.00	15.6
625.	14.20	17.0
550.	16.00	19.2
450.	17.70	21.2
250.	21.20	25.4
0.	22.70	27.2

FAN NO. 12 HAS THE FOLLOWING 7 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
730.	.00	.0
720.	18.90	22.7
610.	21.20	25.4
480.	23.60	28.3
320.	26.00	31.2
115.	28.30	34.0
0.	29.30	35.2

FAN NO. 13 HAS THE FOLLOWING 8 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
2370.	.00	.0
2340.	28.40	34.1
2240.	33.00	39.6
1990.	38.60	46.3
1495.	44.40	53.3
995.	48.20	57.8
500.	50.00	60.0
0.	51.00	61.2

FAN NO. 14 HAS THE FOLLOWING 7 CHARACTERISTIC POINTS AT OPERATING DENSITY OF 1.2000 KG/M3

PRESSURE (PA)	QUANTITY (M3/S)	DRY AIR MASSFLOW (KG/S)
2290.	.00	.0
2270.	54.70	65.6
1745.	65.10	71.1

1245.
745.
375.
0.
72.70
79.30
83.10
84.00
07.2
95.2
99.7
100.8

NATURAL VENTILATION ENERGY DATA

DEPTH BELOW DATUM (M) NATURAL VENTILATION ENERGY (NM/KG)

3.00 .010

INITIAL NETWORK BRANCH DATA

BRANCH NUMBER	FROM	TO	TYPE	RESISTANCE <AT OPERATING <NS2/MB>	QUANTITY <M3/S>	OPERATING DENSITY <KG/M3>	DRY AIR MASS FLOW <KG/S>	MOISTURE CONTENT <G/KG>	BRANCH ELEVATION <IN METRES> FROM TO
1	2	1	8	.000000	170.00	1.2000	204.00	.0	.0
2	3	2	2	.004420	170.00	1.2000	204.00	.0	.0
3	4	3	2	.003090	153.33	1.2000	184.00	.0	250.0
4	5	4	2	.002120	135.00	1.2000	162.00	.0	250.0
5	6	5	2	.000500	126.67	1.2000	152.00	.0	545.0
6	7	6	2	.002650	108.33	1.2000	130.00	.0	575.0
7	1	8	8	.000000	275.00	1.2000	330.00	.0	575.0
8	8	9	2	.001820	275.00	1.2000	330.00	.0	.0
9	9	10	2	.000328	256.67	1.2000	308.00	.0	250.0
10	10	11	2	.000328	250.00	1.2000	300.00	.0	295.0
11	11	12	2	.000328	245.00	1.2000	294.00	.0	340.0
12	12	13	2	.000291	231.67	1.2000	278.00	.0	305.0
13	13	14	2	.000546	201.67	1.2000	242.00	.0	425.0
14	14	15	2	.000218	161.67	1.2000	194.00	.0	500.0
15	15	16	2	.000328	143.33	1.2000	172.00	.0	530.0
16	16	17	2	.001780	86.67	1.2000	104.00	.0	575.0
17	17	18	2	.000218	55.00	1.2000	66.00	.0	820.0
18	19	1	8	.000000	500.00	1.2000	600.00	.0	850.0
19	20	19	2	.004050	500.00	1.2000	600.00	.0	.0
20	21	20	2	.001010	481.67	1.2000	578.00	.0	380.0
21	22	21	2	.001070	380.00	1.2000	456.00	.0	475.0
22	23	22	2	.001600	271.67	1.2000	326.00	.0	575.0
23	24	23	2	.001330	116.67	1.2000	140.00	.0	725.0
24	1	25	8	.000000	550.00	1.2000	660.00	.0	.0
25	25	26	2	.003820	550.00	1.2000	660.00	.0	475.0
26	26	27	2	.001410	523.33	1.2000	628.00	.0	650.0
27	27	28	2	.000482	453.33	1.2000	544.00	.0	710.0
28	28	29	2	.000764	241.67	1.2000	290.00	.0	805.0
29	29	30	2	.000121	215.00	1.2000	258.00	.0	890.0
30	30	31	2	.000121	120.00	1.2000	144.00	.0	1025.0
31	31	32	2	.000724	113.33	1.2000	136.00	.0	925.0
32	32	33	2	.000600	60.00	1.2000	82.00	.0	1000.0
33	33	1	8	.000000	61.67	1.2000	74.00	.0	.0

91	73	-	68	2	.028000	40.00	1.2000	48.00	.0	400.0	475.0
92	74	-	73	2	.007300	40.00	1.2000	48.00	.0	495.0	480.0
93	75	-	74	2	.006100	30.00	1.2000	36.00	.0	495.0	495.0
94	75	-	76	2	.001400	10.00	1.2000	12.00	.0	495.0	495.0
95	14	-	76	2	.150000	40.00	1.2000	48.00	.0	495.0	495.0
96	76	-	77	2	.008500	33.33	1.2000	40.00	.0	495.0	495.0
97	77	-	72	2	.006700	16.67	1.2000	20.00	.0	495.0	480.0
98	77	-	78	2	.021000	28.33	1.2000	34.00	.0	495.0	495.0
99	77	-	80	2	.003600	5.00	1.2000	6.00	.0	495.0	510.0
100	78	-	79	2	.009500	31.67	1.2000	38.00	.0	495.0	495.0
101	79	-	71	2	.021000	18.33	1.2000	22.00	.0	495.0	475.0
102	79	-	71	2	.070000	13.33	1.2000	16.00	.0	495.0	475.0
103	80	-	81	2	.018000	20.00	1.2000	24.00	.0	510.0	510.0
104	81	-	71	2	.054000	26.67	1.2000	32.00	.0	510.0	475.0
105	82	-	74	2	.044000	10.00	1.2000	12.00	.0	510.0	495.0
106	82	-	75	2	.005100	40.00	1.2000	48.00	.0	530.0	530.0
107	15	-	83	2	.550000	18.33	1.2000	22.00	.0	530.0	530.0
108	83	-	85	2	.003700	3.33	1.2000	4.00	.0	530.0	510.0
109	83	-	80	2	.007900	15.00	1.2000	18.00	.0	530.0	530.0
110	84	-	85	2	.022000	1.67	1.2000	2.00	.0	530.0	530.0
111	84	-	81	2	.042000	6.67	1.2000	8.00	.0	530.0	510.0
112	85	-	86	2	.004600	5.00	1.2000	6.00	.0	530.0	545.0
113	86	-	84	2	.026000	8.33	1.2000	10.00	.0	545.0	530.0
114	87	-	5	2	6.000000	8.33	1.2000	10.00	.0	545.0	545.0
115	87	-	82	2	.017000	50.00	1.2000	60.00	.0	545.0	510.0
116	88	-	87	2	.006300	58.33	1.2000	70.00	.0	560.0	545.0
117	16	-	89	2	.070000	56.67	1.2000	68.00	.0	575.0	575.0
118	89	-	90	2	.006800	36.67	1.2000	44.00	.0	575.0	575.0
119	89	-	92	2	.006100	20.00	1.2000	24.00	.0	575.0	560.0
120	90	-	88	2	.005900	40.00	1.2000	48.00	.0	575.0	575.0
121	91	-	90	2	.008800	3.33	1.2000	4.00	.0	575.0	575.0
122	91	-	95	2	.014000	10.00	1.2000	12.00	.0	575.0	575.0
123	92	-	91	2	.009000	13.33	1.2000	16.00	.0	575.0	575.0
124	92	-	94	2	.005800	6.67	1.2000	8.00	.0	575.0	575.0
125	93	-	6	2	.002000	120.00	1.2000	144.00	.0	575.0	575.0
126	94	-	86	2	.001400	3.33	1.2000	4.00	.0	575.0	545.0
127	94	-	105	2	.007700	3.33	1.2000	4.00	.0	575.0	595.0
128	95	-	93	2	1.000000	18.33	1.2000	22.00	.0	575.0	575.0
129	95	-	88	2	.084000	18.33	1.2000	22.00	.0	575.0	560.0
130	96	-	95	2	.003100	3.33	1.2000	4.00	.0	575.0	575.0
131	96	-	99	2	.015000	6.67	1.2000	8.00	.0	575.0	575.0
132	97	-	98	8	.000000	25.00	1.2000	30.00	.0	575.0	575.0
133	98	-	102	2	.010000	86.67	1.2000	104.00	.0	575.0	575.0
134	99	-	98	2	.006800	41.67	1.2000	50.00	.0	575.0	575.0
135	100	-	99	2	.005500	15.00	1.2000	18.00	.0	575.0	575.0
136	101	-	98	2	.001000	13.33	1.2000	16.00	.0	575.0	575.0
137	102	-	22	2	.050000	108.33	1.2000	130.00	.0	575.0	575.0
138	103	-	104	2	.008500	13.33	1.2000	16.00	.0	605.0	605.0
139	103	-	105	2	.002000	10.00	1.2000	12.00	.0	605.0	605.0
140	104	-	110	2	.000500	13.33	1.2000	16.00	.0	605.0	625.0
141	105	-	111	2	.056000	13.33	1.2000	16.00	.0	605.0	625.0
142	106	-	107	2	.006300	40.00	1.2000	48.00	.0	625.0	625.0
143	106	-	103	2	.004500	23.33	1.2000	28.00	.0	625.0	645.0
144	106	-	113	2	.005000	6.67	1.2000	8.00	.0	625.0	625.0
145	107	-	109	2	.017000	8.33	1.2000	10.00	.0	625.0	625.0
146	107	-	111	2	.000500	41.67	1.2000	30.00	.0	625.0	625.0
147	109	-	110	2	.014000	10.00	1.2000	12.00	.0	625.0	625.0

148	110	-	96	130000	10.00	1.2000	12.00	625.0	575.0
149	110	-	114	.014000	13.33	1.2000	16.00	625.0	645.0
150	27	-	106	.050000	70.00	1.2000	84.00	625.0	625.0
151	111	-	112	.013000	45.00	1.2000	54.00	625.0	625.0
152	112	-	99	.062000	20.00	1.2000	24.00	625.0	575.0
153	112	-	97	.065000	25.00	1.2000	30.00	625.0	625.0
154	113	-	116	.026000	13.33	1.2000	16.00	645.0	665.0
155	114	-	95	.150000	15.00	1.2000	18.00	665.0	665.0
156	115	-	114	.005500	1.67	1.2000	2.00	665.0	575.0
157	115	-	95	.082000	8.33	1.2000	10.00	665.0	665.0
158	116	-	117	.001000	11.67	1.2000	14.00	665.0	665.0
159	116	-	118	.016000	1.67	1.2000	2.00	665.0	665.0
160	117	-	119	.001000	11.67	1.2000	14.00	665.0	665.0
161	118	-	37	5.000000	5.00	1.2000	6.00	645.0	625.0
162	118	-	113	.006300	6.67	1.2000	8.00	665.0	665.0
163	119	-	109	.022000	1.67	1.2000	2.00	665.0	625.0
164	119	-	115	.045000	10.00	1.2000	12.00	665.0	645.0
165	120	-	118	.007200	10.00	1.2000	12.00	685.0	665.0
166	120	-	121	.010000	35.00	1.2000	42.00	685.0	685.0
167	120	-	122	.031000	16.67	1.2000	20.00	685.0	685.0
168	121	-	123	.022000	45.00	1.2000	54.00	685.0	685.0
169	122	-	101	.100000	1.67	1.2000	2.00	685.0	575.0
170	122	-	100	.120000	3.33	1.2000	4.00	685.0	575.0
171	122	-	100	.130000	11.67	1.2000	14.00	685.0	575.0
172	123	-	124	.020000	46.67	1.2000	56.00	685.0	685.0
173	124	-	98	.088000	6.67	1.2000	8.00	685.0	575.0
174	124	-	101	.044000	11.67	1.2000	14.00	685.0	575.0
175	124	-	137	.002000	56.67	1.2000	68.00	685.0	725.0
176	28	-	125	12.000000	211.67	1.2000	254.00	705.0	705.0
177	125	-	41	.005000	5.00	1.2000	6.00	705.0	705.0
178	125	-	126	.010000	111.67	1.2000	134.00	705.0	850.0
179	125	-	157	.020000	95.00	1.2000	114.00	705.0	685.0
180	126	-	121	.020000	10.00	1.2000	12.00	705.0	705.0
181	126	-	127	.011000	3.33	1.2000	4.00	705.0	705.0
182	126	-	128	.020000	93.33	1.2000	112.00	705.0	725.0
183	126	-	139	.040000	5.00	1.2000	6.00	705.0	685.0
184	127	-	123	.040000	1.67	1.2000	2.00	705.0	725.0
185	127	-	137	.022000	61.67	1.2000	74.00	705.0	685.0
186	128	-	138	.025000	31.67	1.2000	38.00	705.0	725.0
187	128	-	130	.000000	63.33	1.2000	76.00	725.0	725.0
188	129	-	131	.003700	16.67	1.2000	20.00	725.0	725.0
189	130	-	131	.004000	46.67	1.2000	56.00	725.0	725.0
190	130	-	132	.025000	108.33	1.2000	130.00	725.0	725.0
191	131	-	7	.015000	103.33	1.2000	124.00	725.0	725.0
192	132	-	134	.010000	23.33	1.2000	28.00	725.0	725.0
193	133	-	132	.034000	5.00	1.2000	6.00	725.0	725.0
194	134	-	124	.001000	98.33	1.2000	118.00	725.0	725.0
195	134	-	136	1.500000	23.33	1.2000	28.00	725.0	725.0
196	135	-	124	.000000	23.33	1.2000	28.00	725.0	725.0
197	136	-	135	.014000	75.00	1.2000	90.00	725.0	725.0
198	136	-	137	.008000	155.00	1.2000	186.00	725.0	575.0
199	137	-	23	.055000	11.67	1.2000	14.00	725.0	725.0
200	138	-	94	2.000000	3.33	1.2000	4.00	725.0	725.0
201	138	-	38	.011000	16.67	1.2000	20.00	725.0	725.0
202	138	-	139	.021000	21.67	1.2000	26.00	725.0	725.0
203	139	-	137	.006.000	91.67	1.2000	111.00	725.0	725.0
204	140	-	131						

205	29	-	141	2	1800000	26.67	1.2000	32.00	.0	775.0	775.0
206	141	-	42	2	12.000000	5.00	1.2000	6.00	.0	775.0	775.0
207	141	-	145	2	.007300	21.67	1.2000	26.00	.0	775.0	800.0
208	142	-	146	2	.003500	53.33	1.2000	64.00	.0	800.0	800.0
209	17	-	142	2	.200000	31.67	1.2000	38.00	.0	800.0	800.0
210	143	-	142	2	.005000	21.67	1.2000	26.00	.0	800.0	800.0
211	143	-	146	2	.005500	10.00	1.2000	12.00	.0	800.0	800.0
212	30	-	144	2	.015000	95.00	1.2000	114.00	.0	800.0	800.0
213	144	-	143	2	.001000	31.67	1.2000	38.00	.0	800.0	800.0
214	144	-	145	2	.007000	1.67	1.2000	2.00	.0	800.0	800.0
215	144	-	147	2	.011000	61.67	1.2000	74.00	.0	800.0	825.0
216	145	-	151	8	.023000	23.33	1.2000	28.00	.0	800.0	825.0
217	146	-	133	2	.110000	16.67	1.2000	20.00	.0	800.0	825.0
218	146	-	133	2	.110000	6.67	1.2000	8.00	.0	825.0	725.0
219	146	-	140	2	.140000	43.33	1.2000	52.00	.0	825.0	725.0
220	146	-	140	2	.140000	48.33	1.2000	58.00	.0	825.0	750.0
221	146	-	129	2	.100000	63.33	1.2000	76.00	.0	825.0	750.0
222	146	-	132	2	.110000	33.33	1.2000	40.00	.0	825.0	725.0
223	147	-	148	2	.001000	26.67	1.2000	32.00	.0	825.0	825.0
224	147	-	150	2	.009500	35.00	1.2000	42.00	.0	825.0	825.0
225	148	-	149	2	.007500	33.33	1.2000	40.00	.0	825.0	825.0
226	31	-	148	2	3.000000	6.67	1.2000	8.00	.0	825.0	825.0
227	149	-	146	2	.008000	43.33	1.2000	52.00	.0	825.0	825.0
228	150	-	146	2	.003000	15.00	1.2000	18.00	.0	825.0	825.0
229	150	-	151	2	.015000	20.00	1.2000	24.00	.0	825.0	825.0
230	151	-	146	2	.001000	43.33	1.2000	52.00	.0	825.0	825.0
231	152	-	146	2	.004000	3.33	1.2000	4.00	.0	825.0	825.0
232	18	-	156	2	.100000	55.00	1.2000	66.00	.0	850.0	850.0
233	156	-	152	2	.015000	31.67	1.2000	38.00	.0	850.0	850.0
234	156	-	159	2	.012000	23.33	1.2000	28.00	.0	850.0	850.0
235	157	-	43	2	8.000000	8.33	1.2000	10.00	.0	850.0	850.0
236	157	-	158	2	.012000	48.33	1.2000	58.00	.0	850.0	850.0
237	157	-	159	2	.009000	38.33	1.2000	46.00	.0	850.0	850.0
238	158	-	159	2	.005000	.00	1.2000	.00	.0	850.0	850.0
239	158	-	160	2	.008000	28.33	1.2000	34.00	.0	850.0	850.0
240	157	-	39	2	2.500000	11.67	1.2000	14.00	.0	850.0	850.0
241	159	-	149	2	.005000	.00	1.2000	.00	.0	850.0	825.0
242	159	-	164	2	.036000	41.67	1.2000	50.00	.0	850.0	900.0
243	159	-	170	2	.005000	.00	1.2000	.00	.0	850.0	825.0
244	160	-	146	2	.031000	15.00	1.2000	18.00	.0	850.0	850.0
245	160	-	161	2	.100000	13.33	1.2000	16.00	.0	850.0	850.0
246	161	-	24	2	.015000	116.67	1.2000	140.00	.0	850.0	850.0
247	162	-	161	2	.005000	103.33	1.2000	124.00	.0	850.0	850.0
248	32	-	163	2	.060000	45.00	1.2000	54.00	.0	925.0	925.0
249	163	-	164	2	.008000	41.67	1.2000	50.00	.0	925.0	925.0
250	163	-	169	2	.500000	3.33	1.2000	4.00	.0	925.0	925.0
251	164	-	165	2	.003000	83.33	1.2000	100.00	.0	925.0	925.0
252	165	-	168	2	.005000	.00	1.2000	.00	.0	925.0	925.0
253	165	-	176	2	.005000	.00	1.2000	.00	.0	925.0	1000.0
254	168	-	44	2	5.000000	8.33	1.2000	10.00	.0	925.0	925.0
255	168	-	192	2	.005000	.00	1.2000	.00	.0	925.0	1000.0
256	169	-	168	2	.005000	.00	1.2000	.00	.0	925.0	925.0
257	170	-	39	2	.002000	15.00	1.2000	18.00	.0	900.0	850.0
258	170	-	40	2	.002000	15.00	1.2000	18.00	.0	900.0	850.0
259	171	-	176	2	.008000	45.00	1.2000	54.00	.0	925.0	1000.0
260	171	-	193	2	.005000	18.33	1.2000	22.00	.0	925.0	925.0
261	172	-	193	2	.006000	70.00	1.2000	114.00	.0	1000.0	925.0

262	33	-	173	2	.025000	68.33	1.2000	82.00	.0	1000.0	1000.0
263	173	-	174	2	.003000	33.33	1.2000	40.00	.0	1000.0	1000.0
264	173	-	175	2	.010000	35.00	1.2000	42.00	.0	1000.0	1000.0
265	174	-	172	2	.007000	48.33	1.2000	58.00	.0	1000.0	1000.0
266	175	-	176	2	.002000	6.67	1.2000	8.00	.0	1000.0	1000.0
267	175	-	180	2	.052000	28.33	1.2000	34.00	.0	1000.0	1125.0
268	176	-	177	2	.003000	51.67	1.2000	62.00	.0	1000.0	1000.0
269	177	-	174	2	.004000	15.00	1.2000	18.00	.0	1000.0	1000.0
270	177	-	172	2	.009000	36.67	1.2000	44.00	.0	1000.0	1000.0
271	177	-	192	2	.005000	.00	1.2000	.00	.0	1000.0	1000.0
272	178	-	179	8	.000000	81.67	1.2000	98.00	.0	1000.0	1000.0
273	179	-	191	8	.000000	81.67	1.2000	98.00	.0	1000.0	1000.0
274	180	-	181	2	.003000	16.67	1.2000	20.00	.0	1125.0	1125.0
275	180	-	182	2	.001000	11.67	1.2000	14.00	.0	1125.0	1125.0
276	181	-	184	2	.050000	55.00	1.2000	66.00	.0	1125.0	1200.0
277	182	-	178	2	.005000	81.67	1.2000	98.00	.0	1125.0	1200.0
278	183	-	182	8	.000000	70.00	1.2000	84.00	.0	1125.0	1125.0
279	184	-	183	2	.050000	70.00	1.2000	84.00	.0	1200.0	1125.0
280	185	-	186	8	.000000	38.33	1.2000	46.00	.0	1375.0	1375.0
281	186	-	181	2	.048000	38.33	1.2000	46.00	.0	1375.0	1125.0
282	46	-	185	2	.002000	38.33	1.2000	46.00	.0	1275.0	1375.0
283	172	-	162	2	.005000	.00	1.2000	.00	.0	975.0	850.0
284	44	-	189	2	.005000	53.33	1.2000	64.00	.0	925.0	1125.0
285	189	-	190	8	.005000	53.33	1.2000	64.00	.0	1125.0	1125.0
286	190	-	45	2	.005000	53.33	1.2000	64.00	.0	1125.0	1200.0
287	191	-	194	2	.500000	81.67	1.2000	98.00	.0	1000.0	.0
288	192	-	162	2	.005000	.00	1.2000	.00	.0	1000.0	875.0
289	192	-	172	2	.005000	.00	1.2000	.00	.0	1000.0	1000.0
290	193	-	162	2	.005000	.00	1.2000	.00	.0	975.0	875.0
291	193	-	162	2	.005000	.00	1.2000	.00	.0	975.0	875.0
292	194	-	1	8	.000000	81.67	1.2000	98.00	.0	.0	.0

NETWORK FAN DATA

IDENTITY NUMBER OF FAN	BRANCH FROM	TO	NUMBER OF CHARACTERISTIC POINTS	ESTIMATED FAN PRESSURE <PA>	STALLING VOLUME <M3/5>	STALLING RESISTANCE <NS2/MB>
1	1	25	9	2500.0	.1	50.0000
2	19	1	10	1800.0	.1	50.0000
3	1	8	5	900.0	.1	50.0000
4	2	1	7	300.0	.1	50.0000
5	183	182	10	50.0	.1	50.0000
6	129	130	7	750.0	.1	50.0000
7	179	191	8	2500.0	.1	50.0000
8	178	179	8	2500.0	.1	50.0000
9	185	186	9	750.0	.1	50.0000
10	136	135	6	1000.0	.1	50.0000
11	145	151	7	600.0	.1	1.0000
12	97	98	7	600.0	.1	1.0000
13	189	190	8	2000.0	.1	50.0000
14	194	1	7	1200.0	.1	50.0000

RESULTS

INITIAL NETWORK

FANS

FAN NUMBER	BRANCH FROM TO	OPERATING PRESSURE (PA)	OPERATING QUANTITY (M3/S)	DRY AIR MASS FLOW (KG/S)	STALLING VOLUME (M3/S)	STALL DISCREPANCY (%)	AIR POWER (KW)
1	1 - 25	2902.	619.5	743.5	.10	619447.6	1797.68
2	19 - 1	1708.	552.3	662.7	.10	552156.9	943.03
3	1 - 8	1200.	313.9	376.6	.10	313761.5	376.63
4	2 - 1	586.	221.6	266.0	.10	221547.2	129.80
5	183 - 182	422.	73.6	88.3	.10	73499.1	31.09
6	129 - 130	514.	76.7	92.0	.10	76579.4	39.38
7	179 - 191	2500.	116.6	140.0	.10	116529.1	291.53
*** THIS QUANTITY IS NOT ON FAN CHARACTERISTIC CURVE---							
8	178 - 179	2500.	116.6	140.0	.10	116529.1	291.53
*** THIS QUANTITY IS NOT ON FAN CHARACTERISTIC CURVE---							
9	185 - 186	750.	134.5	161.3	.10	134352.0	100.84
*** THIS QUANTITY IS NOT ON FAN CHARACTERISTIC CURVE---							
10	136 - 135	853.	23.4	28.1	.10	23331.9	19.99
11	145 - 151	599.	145.8	175.0	.10	145727.4	87.32
*** THIS QUANTITY IS NOT ON FAN CHARACTERISTIC CURVE---							
12	97 - 98	599.	92.1	110.5	.10	92003.5	55.15
*** THIS QUANTITY IS NOT ON FAN CHARACTERISTIC CURVE---							
13	189 - 190	1999.	149.5	179.3	.10	149352.0	298.78
*** THIS QUANTITY IS NOT ON FAN CHARACTERISTIC CURVE---							
14	194 - 1	1199.	116.6	140.0	.10	116529.1	139.81
*** THIS QUANTITY IS NOT ON FAN CHARACTERISTIC CURVE---							

BRANCHES

BRANCH NUMBER	FROM TO	FRICTIONAL PRESSURE DROP (PA)	QUANTITY (M3/S)	RESISTANCE (NS2/MB)	DRY AIR MASS FLOW (KG/S)	OPERATING DENSITY (KG/M3)	AIR POWER (KW)
1	2- 1	0	221.65	.0000	265.98	1.2000	.00
2	3- 2	216	221.65	.0044	265.98	1.2000	47.08
3	4- 3	122	199.73	.0031	239.67	1.2000	24.45
4	5- 4	75	189.49	.0021	227.39	1.2000	14.33
5	6- 5	15	178.57	.0005	214.29	1.2000	2.79
6	7- 6	61	152.76	.0026	183.31	1.2000	9.05
7	1- 8	0	313.86	.0000	376.63	1.2000	.00
8	8- 9	120	313.86	.0010	376.63	1.2000	56.12
9	9- 10	27	292.96	.0003	351.56	1.2000	8.09
10	10- 11	26	205.92	.0003	243.11	1.2000	7.55

11	11-12	25	279.07	.0003	334.89	1.2000	7.03
12	12-13	19	263.49	.0003	316.19	1.2000	5.06
13	13-14	27	227.39	.0005	272.87	1.2000	6.28
14	14-15	6	179.06	.0002	214.87	1.2000	1.07
15	15-16	7	154.21	.0003	185.05	1.2000	1.11
16	16-17	13	86.50	.0018	103.80	1.2000	1.14
17	17-18	0	50.36	.0002	60.43	1.2000	.00
18	18-19	0	552.26	.0000	662.71	1.2000	.00
19	20-19	1234	552.26	.0041	662.71	1.2000	681.93
20	21-20	288	534.35	.0010	641.22	1.2000	153.89
21	22-21	195	428.08	.0011	513.70	1.2000	83.73
22	23-22	175	331.12	.0016	397.35	1.2000	58.01
23	24-23	27	145.07	.0013	174.08	1.2000	4.00
24	1-25	0	619.55	.0000	743.46	1.2000	.00
25	25-26	1465	619.55	.0038	743.46	1.2000	907.76
26	26-27	495	592.93	.0014	711.52	1.2000	293.86
27	27-28	124	508.98	.0005	610.77	1.2000	63.52
28	28-29	52	263.53	.0008	316.24	1.2000	13.91
29	29-30	6	226.09	.0001	271.30	1.2000	1.36
30	30-31	1	124.62	.0001	149.54	1.2000	.15
31	31-32	9	117.51	.0007	141.01	1.2000	1.13
32	32-33	2	71.26	.0006	85.51	1.2000	.17
33	34-1	238	104.41	.0220	125.29	1.2000	24.93
34	35-34	32	98.73	.0034	118.47	1.2000	3.20
35	36-35	57	95.37	.0064	114.44	1.2000	5.49
36	37-36	160	92.22	.0190	110.67	1.2000	14.83
37	38-37	26	88.74	.0034	106.48	1.2000	2.34
38	39-38	67	84.87	.0094	101.84	1.2000	5.70
39	40-39	2	30.01	.0038	36.01	1.2000	.07
40	1-41	510	101.01	.0500	121.21	1.2000	51.51
41	41-42	80	111.03	.0066	133.23	1.2000	8.93
42	42-43	45	120.61	.0032	144.73	1.2000	5.50
43	43-44	93	133.14	.0053	159.77	1.2000	12.46
44	45-46	94	134.45	.0053	161.34	1.2000	12.75
45	9-47	523	20.90	1.2000	25.08	1.2000	10.93
46	47-48	1	9.99	.0140	11.99	1.2000	.01
47	48-49	0	9.99	.0050	11.99	1.2000	.00
48	47-50	0	10.91	.0030	13.09	1.2000	.00
49	50-49	1	13.60	.0080	16.32	1.2000	.02
50	49-3	864	21.92	1.8000	26.30	1.2000	18.94
51	50-51	0	-1.02	.0120	-1.23	1.2000	.00
52	51-55	0	.34	.0210	.41	1.2000	.00
53	52-51	0	1.36	.0030	1.63	1.2000	.00
54	10-52	495	7.04	10.0000	8.45	1.2000	3.49
55	52-34	258	5.68	8.0000	6.82	1.2000	1.47
56	11-54	468	6.85	10.0000	8.22	1.2000	3.21
57	54-55	0	3.49	.0070	4.19	1.2000	.00
58	54-35	224	3.36	20.0000	4.03	1.2000	.75
59	55-57	0	3.83	.0170	4.60	1.2000	.00
60	12-56	411	15.58	1.7000	18.70	1.2000	6.41
61	56-64	0	-2.96	.0042	-3.55	1.2000	.00
62	56-57	0	10.54	.0000	12.55	1.2000	.00

63	57-	4	22.37	.0100	26.85	1.2000	.11
64	58-	492	19.48	1.3000	23.37	1.2000	9.58
65	59-	0	12.22	.0068	14.67	1.2000	.00
66	59-	0	-46	.0020	-55	1.2000	.00
67	60-	1	11.30	.0170	13.56	1.2000	.01
68	61-	1	16.42	.0085	19.70	1.2000	.02
69	62-	961	17.91	3.0000	21.49	1.2000	17.22
70	71-	2	1.49	1.5000	1.79	1.2000	.00
71	61-	0	-5.12	.0440	-6.15	1.2000	.00
72	67-	13	11.76	.0990	14.11	1.2000	.16
73	67-	13	11.76	.0990	14.11	1.2000	.16
74	13-	390	36.10	.3000	43.32	1.2000	14.08
75	63-	1	20.36	.0034	24.43	1.2000	.02
76	63-	1	13.52	.0119	16.23	1.2000	.02
77	63-	0	2.22	.0125	2.66	1.2000	.00
78	64-	3	17.40	.0125	20.68	1.2000	.06
79	65-	196	3.14	20.0000	3.77	1.2000	.62
80	65-	2	10.38	.0280	12.45	1.2000	.02
81	66-	770	27.77	1.0000	33.33	1.2000	21.40
82	68-	14	29.34	.0170	35.21	1.2000	.42
83	68-	776	12.46	5.0000	14.96	1.2000	9.68
84	69-	0	5.82	.0051	6.98	1.2000	.00
85	69-	8	23.52	.0160	28.23	1.2000	.20
86	26-	920	26.61	1.3000	31.94	1.2000	24.50
87	70-	22	32.43	.0220	38.92	1.2000	.74
88	71-	676	106.26	.0600	127.52	1.2000	71.92
89	72-	3	16.65	.0150	19.99	1.2000	.06
90	72-	14	8.17	.2300	9.81	1.2000	.12
91	73-	8	17.93	.0280	21.52	1.2000	.15
92	74-	1	17.93	.0073	21.52	1.2000	.02
93	75-	0	12.96	.0061	15.55	1.2000	.00
94	75-	0	-9.40	.0014	-11.29	1.2000	.00
95	14-	350	48.33	.1500	58.00	1.2000	16.94
96	76-	3	22.26	.0085	26.71	1.2000	.08
97	77-	3	24.83	.0067	29.79	1.2000	.09
98	77-	19	30.27	.0210	36.33	1.2000	.58
99	77-	0	-16.17	.0036	-19.41	1.2000	.00
100	78-	13	38.45	.0095	46.14	1.2000	.51
101	79-	12	24.84	.0210	29.81	1.2000	.30
102	79-	12	13.61	.0700	16.33	1.2000	.16
103	80-	2	13.58	.0180	16.30	1.2000	.03
104	81-	43	28.54	.0540	34.25	1.2000	1.23
105	82-	0	4.97	.0440	5.97	1.2000	.00
106	82-	0	3.56	.0051	4.27	1.2000	.00
107	15-	339	24.85	.5500	29.82	1.2000	8.44
108	83-	0	-4.90	.0037	-5.88	1.2000	.00
109	83-	6	29.75	.0079	35.70	1.2000	.10
110	84-	0	-6.76	.0220	-8.11	1.2000	.00
111	84-	9	14.96	.0431	17.95	1.2000	.11
112	86-	0	-11.66	.0046	-13.99	1.2000	.00
113	86-	1	8.90	.0031	9.84	1.2000	.01
114	87-	214	101.90	1.0000	111.10	1.2000	2.79

115	87-82	1	8.53	.0170	10.24	1.2000	.01
116	88-87	1	19.45	.0063	23.33	1.2000	.02
117	16-89	320	67.71	.0700	81.25	1.2000	21.69
118	89-90	7	33.71	.0068	40.45	1.2000	.24
119	89-92	6	34.00	.0061	40.80	1.2000	.20
120	90-88	3	25.26	.0059	30.32	1.2000	.09
121	91-90	0	-8.45	.0088	-10.13	1.2000	.00
122	91-95	4	20.55	.0140	24.65	1.2000	.10
123	92-91	1	12.10	.0090	14.52	1.2000	.01
124	92-94	2	21.90	.0058	26.28	1.2000	.05
125	93-6	32	127.48	.0020	152.97	1.2000	4.13
126	94-86	0	19.86	.0014	23.83	1.2000	.00
127	94-105	0	-7.04	.0077	-8.45	1.2000	.00
128	95-93	666	25.81	1.0000	30.97	1.2000	17.19
129	95-88	-2	-5.82	.0840	-6.98	1.2000	.01
130	96-95	0	-12.69	.0031	-15.22	1.2000	.00
131	96-99	4	18.62	.0150	22.35	1.2000	.09
132	97-98	0	92.10	.0000	110.52	1.2000	.00
133	98-102	56	75.29	.0100	90.35	1.2000	4.25
134	99-98	0	2.02	.0068	2.42	1.2000	.00
135	100-99	0	11.46	.0055	13.75	1.2000	.00
136	101-98	0	-5.93	.0010	-7.12	1.2000	.00
137	102-22	469	96.96	.0500	116.35	1.2000	45.49
138	103-104	1	13.59	.0085	16.31	1.2000	.02
139	103-105	0	17.54	.0020	21.05	1.2000	.00
140	104-110	0	13.59	.0005	16.31	1.2000	.00
141	105-111	6	10.50	.0560	12.60	1.2000	.06
142	106-107	9	39.11	.0063	46.93	1.2000	.38
143	106-103	3	31.14	.0045	37.36	1.2000	.11
144	106-113	0	13.71	.0050	16.45	1.2000	.00
145	107-109	-2	-14.43	.0170	-17.31	1.2000	.03
146	107-111	1	53.54	.0005	64.24	1.2000	.06
147	109-110	0	-3.32	.0140	-3.98	1.2000	.00
148	110-96	3	5.94	.1300	7.12	1.2000	.02
149	110-114	0	4.34	.0140	5.20	1.2000	.00
150	27-106	387	83.96	.0550	100.75	1.2000	32.54
151	111-112	52	64.04	.0130	76.85	1.2000	3.38
152	112-99	-48	-28.07	.0620	-33.68	1.2000	1.35
153	112-97	550	92.10	.0650	110.52	1.2000	50.73
154	113-116	1	8.53	.0260	10.23	1.2000	.01
155	114-95	3	5.15	.1500	6.19	1.2000	.02
156	115-114	0	.82	.0055	.98	1.2000	.00
157	115-95	3	6.98	.0820	8.37	1.2000	.03
158	116-117	0	18.90	.0010	22.68	1.2000	.00
159	116-118	-1	-10.38	.0160	-12.45	1.2000	.01
160	117-119	0	18.90	.0010	22.68	1.2000	.00
161	118-37	60	3.49	5.0000	4.19	1.2000	.21
162	118-113	0	-5.18	.0063	-6.22	1.2000	.00
163	119-109	2	11.11	.0220	13.33	1.2000	.03
164	119-115	2	7.80	.0450	9.36	1.2000	.02
165	120-118	0	8.68	.0022	10.42	1.2000	.00
166	120-121	0	-6.14	.0100	7.17	1.2000	.00

167	120-122	9	18.44	.0310	22.13	1.2000	.18
168	121-123	24	33.77	.0220	40.53	1.2000	.81
169	122-101	4	6.98	.1000	8.38	1.2000	.03
170	122-100	3	5.64	.1200	7.01	1.2000	.02
171	122-100	3	5.62	.1300	6.74	1.2000	.02
172	123-124	3	15.38	.0200	18.45	1.2000	.06
173	124-98	-14	-12.89	.0880	-15.47	1.2000	.19
174	124-101	-14	-12.92	.0880	-15.50	1.2000	.19
175	124-137	61	37.43	.0440	44.92	1.2000	2.29
176	28-125	120	245.45	.0020	294.54	1.2000	29.45
177	125-41	1204	10.02	12.0000	12.02	1.2000	12.07
178	125-126	110	148.79	.0050	178.55	1.2000	16.43
179	125-157	74	86.64	.0100	103.96	1.2000	6.45
180	126-121	31	39.91	.0200	47.89	1.2000	1.25
181	126-127	68	18.57	.2000	22.29	1.2000	1.27
182	126-128	21	45.22	.0110	54.26	1.2000	.98
183	126-139	39	45.09	.0200	54.10	1.2000	1.79
184	127-123	-13	-18.39	.0400	-22.07	1.2000	.24
185	127-137	54	36.97	.0400	44.36	1.2000	2.00
186	128-120	9	20.99	.0220	25.18	1.2000	.20
187	128-138	14	24.23	.0250	29.08	1.2000	.35
188	129-130	0	76.68	.0000	92.02	1.2000	.00
189	130-131	37	100.88	.0037	121.05	1.2000	3.75
190	130-132	-1	-24.20	.0040	-29.03	1.2000	.03
191	131-7	583	152.76	.0250	183.31	1.2000	89.09
192	132-134	30	45.03	.0150	54.04	1.2000	1.35
193	133-132	18	43.80	.0100	52.56	1.2000	.79
194	134-124	-24	-27.19	.0340	-32.62	1.2000	.65
195	134-136	4	72.22	.0010	86.66	1.2000	.35
196	135-124	823	23.43	1.5000	28.12	1.2000	19.29
197	136-135	0	23.43	.0000	28.12	1.2000	.00
198	136-137	32	48.79	.0140	58.54	1.2000	1.58
199	137-23	276	186.06	.0080	223.27	1.2000	51.35
200	138-94	0	2.58	.0550	3.10	1.2000	.00
201	138-38	28	3.87	2.0000	4.64	1.2000	.11
202	138-139	2	17.78	.0110	21.34	1.2000	.04
203	139-137	82	62.87	.0210	75.44	1.2000	5.21
204	140-131	16	51.89	.0063	62.27	1.2000	.87
205	29-141	252	37.45	.1800	44.93	1.2000	9.44
206	141-42	1100	9.58	12.0000	11.50	1.2000	10.54
207	141-145	4	27.87	.0073	33.44	1.2000	.13
208	142-146	1	20.79	.0035	24.95	1.2000	.02
209	17-142	260	36.14	.2000	43.37	1.2000	9.41
210	143-142	0	-15.35	.0050	-18.42	1.2000	.00
211	143-146	0	7.77	.0055	9.32	1.2000	.00
212	30-144	153	101.47	.0150	121.76	1.2000	15.59
213	144-143	0	-7.58	.0010	-9.10	1.2000	.00
214	144-145	97	117.96	.0070	141.55	1.2000	11.47
215	144-147	0	-8.91	.0110	-10.70	1.2000	.00
216	145-151	408	145.83	.0230	174.99	1.2000	21.22
217	146-133	52	21.45	.1100	26.34	1.2000	1.16
218	146-133	51	21.15	.1100	26.11	1.2000	1.11

219	146-140	93	25.96	.1400	31.16	1.2000	2.43
220	146-140	93	25.92	.1400	31.11	1.2000	2.43
221	146-129	586	76.68	.1000	92.02	1.2000	45.00
222	146-132	70	25.43	.1100	30.51	1.2000	1.80
223	147-148	0	-3.22	.0010	-3.87	1.2000	.00
224	147-150	0	-5.69	.0095	-6.83	1.2000	.00
225	148-149	0	3.89	.0075	4.66	1.2000	.00
226	31-148	151	7.11	3.0000	8.53	1.2000	1.08
227	149-146	0	12.00	.0080	14.40	1.2000	.00
228	150-146	1	22.83	.0030	27.39	1.2000	.03
229	150-151	-12	-28.52	.0150	-34.22	1.2000	.34
230	151-146	13	117.31	.0010	140.77	1.2000	1.55
231	152-146	0	-3.61	.0040	-4.33	1.2000	.00
232	18-156	253	50.36	.1000	60.43	1.2000	12.75
233	156-152	8	24.72	.0150	29.67	1.2000	.21
234	156-159	7	25.63	.0120	30.76	1.2000	.18
235	157-43	1256	12.54	8.0000	15.04	1.2000	15.75
236	157-158	16	38.06	.0120	45.67	1.2000	.64
237	157-159	16	43.94	.0090	52.73	1.2000	.74
238	158-159	0	-1.08	.0050	-1.30	1.2000	.00
239	158-160	2	19.14	.0080	22.97	1.2000	.05
240	157-39	34	3.77	2.5000	4.52	1.2000	.13
241	159-149	0	-1.89	.0050	-2.27	1.2000	.00
242	159-164	0	-7.72	.0360	-8.86	1.2000	.00
243	159-170	12	51.10	.0050	61.32	1.2000	.61
244	160-146	-1	-7.62	.0310	-9.15	1.2000	.01
245	160-161	70	26.76	.1000	32.11	1.2000	1.89
246	161-24	315	145.07	.0150	174.08	1.2000	45.78
247	162-161	69	118.31	.0050	141.97	1.2000	8.23
248	32-163	127	46.25	.0600	55.50	1.2000	5.88
249	163-164	12	40.32	.0080	48.39	1.2000	.48
250	163-169	16	5.93	.5000	7.11	1.2000	.10
251	164-165	3	39.60	.0030	47.53	1.2000	.14
252	165-168	0	-5.10	.0050	-6.12	1.2000	.00
253	165-176	-7	-38.63	.0050	-46.35	1.2000	.28
254	168-44	1329	16.31	5.0000	19.57	1.2000	21.68
255	168-192	0	-10.48	.0050	-12.58	1.2000	.00
256	169-168	0	2.59	.0050	3.11	1.2000	.00
257	170-39	4	51.09	.0020	61.31	1.2000	.25
258	170-40	1	30.01	.0020	36.01	1.2000	.04
259	171-176	1	16.48	.0088	19.77	1.2000	.02
260	171-193	10	46.86	.0050	56.23	1.2000	.51
261	172-193	1	19.52	.0050	23.43	1.2000	.02
262	33-173	126	71.26	.0250	85.51	1.2000	8.98
263	173-174	8	53.48	.0030	64.18	1.2000	.45
264	173-175	2	17.78	.0100	21.33	1.2000	.04
265	174-172	6	30.43	.0070	36.51	1.2000	.18
266	175-176	4	50.60	.0020	60.72	1.2000	.24
267	175-180	-55	-32.82	.0520	-39.39	1.2000	1.81
268	176-177	2	28.45	.0030	34.14	1.2000	.07
269	177-174	-1	-23.06	.0040	-27.67	1.2000	.01
270	177-172	3	23.00	.0040	26.40	1.2000	.00

271	177-192	3	29.51	.0050	35.41	1.2000	.11
272	178-179	0	116.63	.0000	139.95	1.2000	.00
273	179-191	0	116.63	.0000	139.95	1.2000	.00
274	180-181	-16	-75.85	.0030	-91.02	1.2000	1.27
275	180-182	1	43.03	.0010	51.64	1.2000	.05
276	181-184	171	58.60	.0500	70.32	1.2000	10.06
277	182-178	67	116.63	.0050	139.95	1.2000	7.84
278	183-182	0	73.60	.0000	88.32	1.2000	.00
279	184-183	270	73.60	.0500	88.32	1.2000	19.87
280	185-186	0	134.45	.0000	161.34	1.2000	.00
281	186-181	867	134.45	.0480	161.34	1.2000	116.65
282	46-185	36	134.45	.0020	161.34	1.2000	4.84
283	172-162	1	18.46	.0050	22.15	1.2000	.02
284	44-189	111	149.45	.0050	179.34	1.2000	16.68
285	189-190	111	149.45	.0050	179.34	1.2000	16.68
286	190-45	111	149.45	.0050	179.34	1.2000	16.68
287	191-194	6800	116.63	.5000	139.95	1.2000	793.12
288	192-162	1	18.47	.0050	22.16	1.2000	.02
289	192-172	0	.56	.0050	.67	1.2000	.00
290	193-162	0	-10.98	.0050	-13.17	1.2000	.00
291	193-162	0	-10.98	.0050	-13.17	1.2000	.00
292	194-1	0	116.63	.0000	139.95	1.2000	.00

NUMBER OF ITERATIONS = 98

ENERGY TABLE *****

THE FOLLOWING TABLE GIVES THE ENERGY CONTENT RELATIVE TO .0 NM/KG AT JUNCTION NO. 1
THE TABLE CAN BE USED TO FIND NEUTRAL POINTS AND THE ENERGY AVAILABLE TO PRODUCE FLOW THE VALUE 99999 INDICATES AN INACCESSIBLE

JUNCTION	ENERGY (NM/KG)	JUNCTION	ENERGY (NM/KG)	JUNCTION	ENERGY (NM/KG)	JUNCTION	ENERGY (NM/KG)	JUNCTION	ENERGY (NM/KG)
2	-488.	1	0.	3	-308.	4	-206.	5	-143.
6	-130.	7	-79.	8	1000.	9	851.	10	827.
11	805.	12	784.	13	767.	14	743.	15	738.
16	731.	17	720.	18	719.	19	-1423.	20	-395.
21	-155.	22	8.	23	154.	24	176.	25	2418.
26	1196.	27	783.	28	679.	29	635.	30	630.
31	628.	32	620.	33	617.	34	199.	35	226.
36	275.	37	408.	38	431.	39	487.	40	489.
41	-425.	42	-493.	43	-532.	44	-610.	45	777.
46	698.	47	414.	48	413.	49	413.	50	414.
51	414.	55	414.	52	414.	54	414.	57	414.
56	440.	64	440.	58	410.	59	410.	60	410.
61	409.	62	407.	71	410.	67	422.	63	441.
65	439.	68	441.	66	437.	69	429.	70	429.
72	445.	78	432.	73	449.	74	450.	75	451.
76	451.	77	448.	80	449.	84	454.	86	455.
82	451.	83	454.	85	455.	90	457.	92	458.
87	452.	88	454.	89	464.	93	-103.	105	456.
91	457.	95	452.	94	455.	98	447.	102	400.
96	451.	99	447.	97	-53.	104	455.	110	455.
100	448.	101	447.	103	456.	113	459.	109	455.
111	451.	106	460.	107	452.	115	455.	117	457.
114	455.	112	406.	116	458.	121	460.	122	451.
118	459.	119	457.	120	459.	125	579.	126	486.
123	439.	124	435.	137	383.	139	452.	138	455.
157	516.	127	429.	128	468.	132	442.	134	414.
129	11.	130	440.	131	407.	140	421.	141	424.
133	457.	136	410.	135	1121.	143	501.	144	501.
145	420.	142	502.	146	501.	150	502.	149	502.
152	501.	151	512.	148	502.	158	502.	160	499.
164	502.	156	508.	159	502.	162	498.	163	513.
169	498.	170	491.	161	439.	176	504.	192	499.
171	506.	165	498.	168	498.	173	511.	174	504.
175	509.	193	497.	172	499.	178	498.	179	2581.
191	4664.	180	556.	177	554.	184	427.	183	202.
185	667.	181	570.	182	554.	190	871.	194	-1000.
		186	1292.	189	-703.				

APPENDIX H

FIX SCADA SYSTEM



THE FIX™

The Fully Integrated Control System

from
Intellution

The Catalog of Intelligent Solutions

Introduction

The Industry Standard

In your hands you hold a catalog that describes THE FIX, the most powerful, low-cost distributed automation and control software available today. Look through this guide and you will find state-of-the-art solutions packaged the way you want them — flexible, configurable and understandable. You will be amazed at the high power and low cost of these field-tested and endorsed packages.

Contents

Introduction	1
Overview	2
Database	3
Operator Interface	4
Batch Control	6
Statistical Control	8
I/O Drivers	9
THE FIX ACE	10
Distributed Control	
Network	11
Open Architecture	12
Historical Trending	13
Options and Applications	14
Accessories and Services	15
Product Listings	16

THE FIX is *the industry standard* for PC-based monitoring and control. Built by industry veterans, THE FIX is a flexible set of software modules that lets you select the combination that best fills your needs. This catalog is organized to provide you with an overall understanding of what the various FIX modules do and how they work together. At the end of the catalog you will find a description of each module which will help you pick the best solution for your needs. But before introducing our product, we will introduce ourselves.

Founded in 1980, our staff comes from some of the largest industrial control companies in the business. This experience is evident in our products, which contain the same sophisticated features found in systems costing much more. Not content to simply copy other systems, we have made it a tradition to ask our customers what they need and incorporate their suggestions into new products. These improvements have led to THE FIX's becoming the Industry Standard for PC-based process monitoring and control

software.

Our intelligent approach to software design led us to develop a set of software modules that can be easily configured to a wide variety of industrial applications. A survey of our customer list finds THE FIX in pharmaceuticals, food and beverage, chemicals, and discrete parts manufacturing. We extend beyond the normal definitions of process control to maintain ice temperature for sporting events and to help regulate climate conditions in research labs. Our product has gone from primarily monitoring processes, to controlling processes in both continuous and batch modes. Now THE FIX is a complete distributed control system for factory automation and a key component of CIM.

The factory of the future will contain interconnected flexible processing modules. THE FIX has these features today! In the future, management will use a wide variety of application programs to link accounting, inventory, and senior administrators to the factory floor. THE FIX provides that access today!

THE FIX Catalog of Intelligent Solutions

Overview

THE FIX is.....

THE FIX is the Fully Integrated Control System for IBM industrial and personal computers. Flexible and powerful, THE FIX combines features found on large P.C.S. systems in a PC-based package that is easy to configure and easy to use.

Flexible — THE FIX comes in modules that fit your application, whether that application is monitoring a single cell or complete factory automation. These modules are fully integrated with options that let you look at control in innovative, efficient ways.

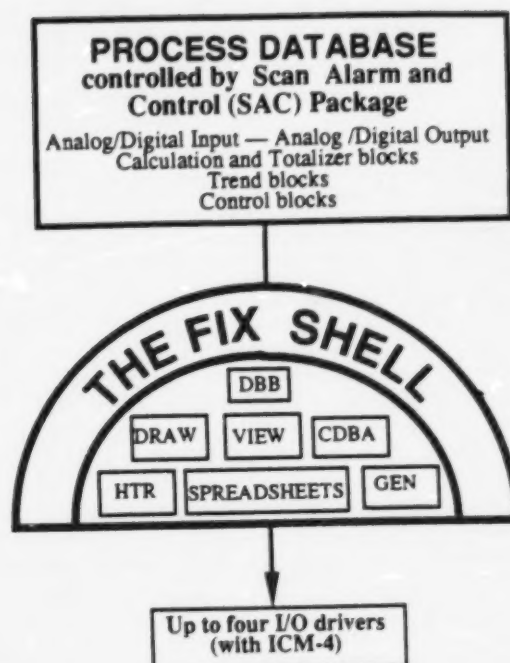
Friendly — THE FIX uses a menu-driven, fill-in-the-blanks approach to configuration. This results in a package that can be implemented with a minimum of training. Tie a number of keystrokes together and link it to a single key with the Key Macro Editor. This results in one-keystroke operations minimizing operator errors and training. THE FIX contains on-line help so you are never more than a single key away from an answer.

Powerful — THE FIX gives you all the control features found on expensive mini and mainframe systems. THE FIX contains a full-featured Batch Control package that allows both sequential and parallel tasking, wait-for and if-go-to statements, plus device blocks to simplify control structures. Changing control parameters and adding new equipment is quick and easy because THE FIX is configured on-line.

Generous — THE FIX shares the computer and the process data with other programs through multitasking and open architecture. Multitasking

*multitasking &
open architecture*

allows you to run different programs simultaneously. Open architecture means that information in the process



database is accessible in real time to both user-written programs and popular application programs such as spreadsheets.

Informative — THE FIX gives you many ways of bringing information to the operator. This results in a man-machine interface that is more than just a graphics display. The high-resolution color graphics are coupled with a number of data links that can

*color graphics and animation
real-time and historical
data displays*

change colors, display messages, and show a new sub-picture according to the state of an input value. You can even animate pictures to show the movement of equipment or material. The Historical Trending package lets you examine your process over time from multiple points with full-color graphics.

How THE FIX Works....

THE FIX system consists of PC-DOS integrated software modules that share a common database and operate under a multitasking shell. These modules are designated as either foreground or background tasks, depending on how they are used by the operator. The processing of information in the database is controlled by the Scan, Alarm and Control (SAC) module, which always resides in memory with the database. The database itself consists of data blocks that are defined in the Database Builder (DBB). Three additional modules make up a core FIX system. They are the I/O Drivers, DRAW, and VIEW. The I/O Driver is the interface with the process equipment, and, once configured, it operates in the background with SAC. The user builds the operator interface with DRAW and runs it with VIEW.

The Database Builder: the foundation of THE FIX

Data Acquisition and Control

The Database Builder (DBB) is the foundation of THE FIX system. It is here that you define the input/control/output loops that monitor and control your process. Comprised of familiar instrumentation blocks, you configure each block by filling in the blanks —

fill-in-the-blanks configuration

no programming is required. In addition, you can build, modify, and tune your process online without losing vital control and alarm scanning.

On-line Configuration — THE FIX lets you build your database online while still controlling your process. You define each block by giving it a unique tagname. Each entry is first checked for proper syntax. Then before the block goes online, DBB checks the block against the rest of the database for error-free integration.

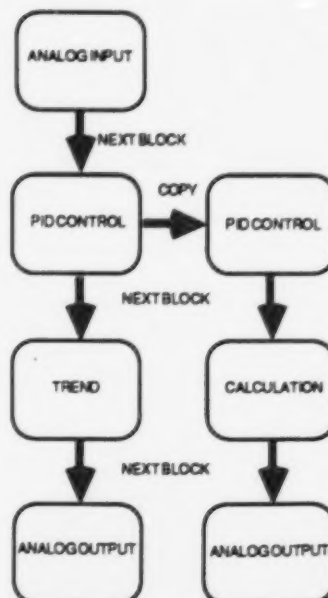
Alarm Handling — THE FIX provides multiple alarm fields on each input block and allows you to direct the signal to any combination of printer, screen, digital contact, or PC speaker. This allows you to turn on a horn, record process deviations, or let the operator know about a production change. All alarms can be set to different priority levels to make it easier for the operator to respond. The alarms can be tied to the speaker in the personal computer to provide up to three levels of audio alarming at the operator's station.

Process Simulation — All of the analog and digital blocks can be used as dummy I/O points for simulating input and output. This allows the user to test and optimize control strategies before going on-line.

On-line Configuration

ANALOG INPUT		DESC...	CONVEYOR SPEED PALLET
TAG.....	CONVYSP		
DV-DEVICE.....	GMM		
HT-HWOPTIONS			
ID-ADDR.....	1:140001		
SC-SIG COND.....	LIN		
EL-LO EGU.....	0.00	LL-LO LO ALM	0.00
EH-HI EGU.....	100.00	AL-LO ALM	10.00
ET-EGUTAG.....	FTSEC	AH-HI ALM	90.00
		PH-HI HI ALM	100.00
		RC-ROC ALM	15.00
		DB-DEAD BAND	5.00
		AP-ALM PRI	L
		AD-ALM DEST	THF
		AE-ALM ENABLE	ENABLE
		CC-ALM CONTACT	DO1
		CM-ALM MODE	NEW
HELP: FOR MORE INFO			
EXIT: LOOP DEFINITION COMPLETE			

Press <F1> for help at any time



Chaining Blocks — Building control loops is easy. Each block asks you where to send its output (next block) and checks to see that the loop is complete before going on-line. The NEXT BLOCK field passes data to a designated downstream block. Cascades are built by using a COPY to field to send the output of the master block to a designated slave block.

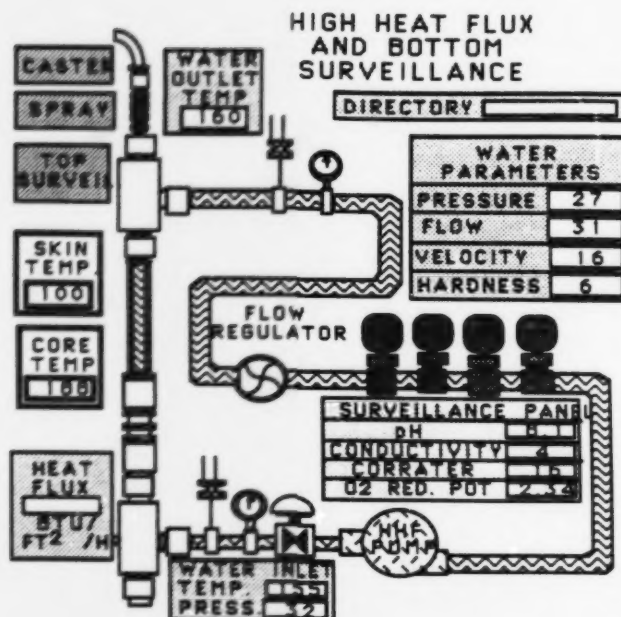
Data Links — Most of the data fields in each database block can be accessed by the user through the VIEW package if properly configured with DRAW. External programs can access data in most database blocks simply by knowing the tagname.

THE FIX Catalog of Intelligent Solutions

Operator Interface

Picture this!

*A man-machine
interface
with
color graphics,
real-time process
data, and
single-key
operation*



THE FIX lets you build detailed process displays with many interactive features for easy, error-free operations. Your FIX package comes with a module for drawing and a module for viewing your displays. There are two graphics packages available for THE FIX, Character Graphics and Pixel Graphics.

Character Graphics — Character Graphics enable you to build displays quickly because the symbols are pre-configured to go together. A downloadable character set gives you over 128 different instrumentation symbols (including horizontal and vertical valves, solenoid and modulated valves, pumps, pipe, ladder logic symbols, tank sides and bar graph segments). The Character Graphics package provides a full 16 foreground and 8 background colors on a standard color monitor with the IBM Color Graphics Adapter (CGA). Character support is also available for the Enhanced Graphics Adapter (EGA).

Pixel Graphics — The Pixel Graphics option provides the ultimate in flexibility and high resolution. Pixel displays are completely free-format. You can draw circles, boxes, lines, and polygons that can then be modified pixel-by-pixel or on a larger scale. You can even build your own set of instrumentation symbols that can be reused in other displays.

An EGA board with 256K of memory must be purchased for Pixel Graphics. It will give you 640- by 350-pixel resolution and 16 foreground and background colors. Incorporating Halo Graphics, THE FIX Pixel Graphics package includes advanced features such as mouse-driven cursor handling. CAD pictures drawn with other software packages can be imported into Pixel Graphics with Dr. Halo.

VIEW — Whether you use Pixel or Character Graphics, VIEW is the FIX module that allows you real-time access to the process database. You interact with the database through data links tied to the display.

Advanced Features — Both the Pixel and Character Graphics packages have many advanced features that help you create easy-to-use operator displays. You can control complex actions with a single keystroke or even simulate equipment movement. A few of the most important features are listed below and on the next page:

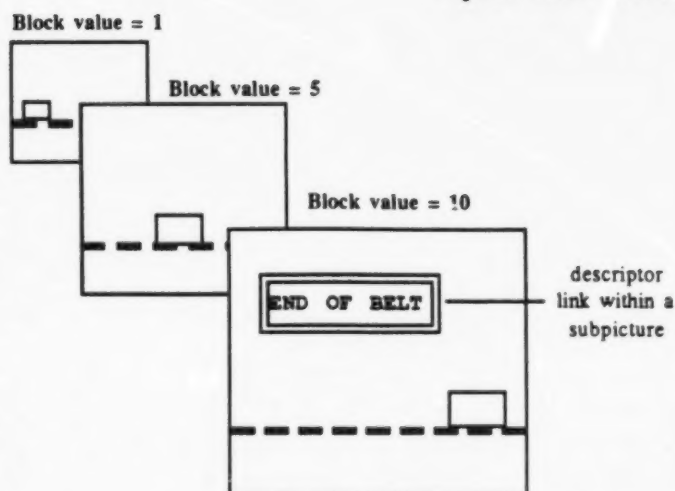
- **Password Protection** — Each display can be locked with a unique password to prevent unauthorized data entry.
- **Display Linkage** — Screens can be tied to other displays, making display call-up intuitive, fast, and easy.
- **Alarm Window** — An alarm window that summarizes current alarms can be placed on any or all displays.
- **Link Selection by Cursor** — You select a link by moving the cursor until it highlights the desired link. This eliminates the need for operators to memorize tagnames.

Operator Interface

• **Tag Group Call-up** — You can look at similar process units with the same display by changing only the unit name. This makes display building easier and lets you emulate the display procedures of large control systems.

• **Dynamic Subpicture Display** — Fetches a subpicture based on the current value of a tag. You can use this link to animate a display to show equipment movement or to provide operator advisories at key process values.

• **Key Macros** — Key macros provide single-key execution of multiple-key operations. They are also a means of creating intuitive, single-keystroke commands. While you might expect this feature only on a more costly system, Intellution provides it at no extra charge.



Your process at work — THE FIX can display your process in motion by linking process values to subpictures. Use descriptor links or other links in your subpictures to give the operator additional information.

	Character Graphics Specifications	Pixel Graphics Specifications
Display Resolution	25 lines by 80 columns	640 horizontal by 350 vertical pixels
Display Technique	Downloadable instrumentation character set	Pixel using embedded graphics interface
Foreground Colors	16	16
Background Colors	8	16
Number of Displays	Limited only by disk space	Limited only by disk space
Maintenance Functions	Add, modify, delete, list displays, list display links	Add, modify, delete, list displays
Drawing Functions	Select foreground color Select background color Read/write subpicture Cut & paste Select character set Erase screen segment Show cut/paste buffer contents Clear screen Add, modify, delete links	Select foreground color Select background color Read/write subpicture Cut & paste Draw circle, box or line Select line style and width Fill polygon with current color Select fill pattern Erase screen segment Undo last command Scale or rotate object Pixel-by-pixel editing Add, modify, delete links
Linking Functions for both Character and Pixel Graphics		
Display measurement	Display setpoint	Display output
Display block status	Measurement bar graph	Setpoint bar graph
Output bar graph	Display block descriptor	Change color on status
Change color on value	Link screen area to picture	Place trend window
Place alarm history window	Place system time and date	Assign function key
Assign password	Define previous/next display	Assign key macro file
Dynamic subpicture display		

Batch Control

Batch Control enables you to build complex control loops that incorporate sequential and parallel tasks. It also makes recipe building and loading easier. Batch Control provides the best of two worlds — rigid standardization and consistency for a single process, and flexibility to run several different processes with the same equipment. The Batch Control package also makes implementing and debugging a control system easier.

Batch Control does all of these things with three powerful features: a Program block, a Device block, and a Recipe package. In addition, Batch Control has all of the modules of the Expanded SCADA package and the Control package (specifications of these packages appear on pages 16 and 17).

The user enters easy-to-use statements into the Program block and Device block to make them execute multi-step tasks. Some of these statements are listed below; refer to the next page for a complete listing.

Sequential & Parallel Tasking

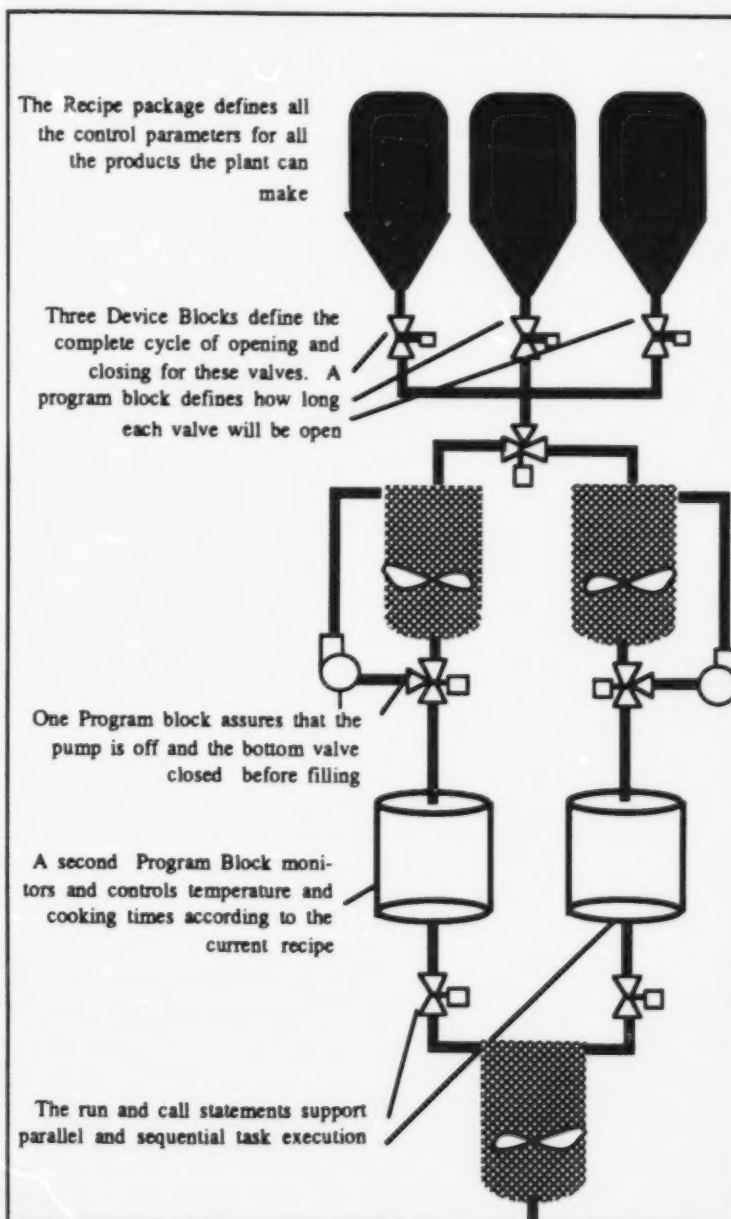
— The CALL statement suspends program processing until a subroutine is completed. The RUN statement executes a subroutine in parallel.

Wait Statements — There are three different wait statements in the Program block. One waits for a specified period of time, another waits for a block to reach a designated status, and a third waits for a particular condition to occur. A fourth statement provides "time-out" capability for wait statements.

Change Parameters Statements

— The Program block can set control parameters in other database blocks and can open or close digital outputs.

*The most complete PC-based
control package available
also makes
recipe building and loading effortless*



Batch Control

Program Block Specifications

Number of Steps	20 per block; blocks can be chained if more than 20 steps are desired Up to 999 or the limit allowed by memory
Number of Blocks	
Control Statements	
RUN<tag>	Execute the named block in parallel (return while running)
CALL<tag>	Execute the named block in series (return when complete)
STOP<tag>	Stop the named block
END<tag>	Stop this program block
SETAUTO<tag>	Place the named block in automatic mode
SETMANL<tag>	Place the named block in manual mode
WAITSTAT<tag, status>	Wait for the named block to reach a specified status
SETERROR	Set the error code for this program block
CLRERROR	Clear the error code for this program block
SETDEBUG	Execute one program step per second and print the step number
CLRDEBUG	Exit the debug mode
Parameter Change Statements	
CLOSE<tag>	Close the digital input/output block
OPEN<tag>	Open the digital input/output block
SETTARG<tag><value>	Set the target value of a Ramp block, the setpoint of a PID control block, or the bias of a Ratio/Bias block
SETOUT<tag><value>	Set the output of an Analog output, Ramp, or PID control block
SETTIME<tag><value>	Set the ramp time of a Ramp block or the delay time of a Device block
Wait Statements	
WAITFOR<expression>	Wait for a condition to occur
MAXWAIT<time>	Specify how long to wait for a condition to occur
DELAY<time>	Wait for "n" seconds (up to 32000)
Test and Jump Statements	
IF<expression>GOTO	Compares items or values. If condition is satisfied, control will pass to the specified block
SETLIM<pct>	Set the comparison limit (deadband) for "equals"
IFTIME GOTO	Go to the named statement if the WAITFOR time limit expires
GOTO	Unconditional Goto statement
Miscellaneous Statements	
Message<string>	Output a 40-character message
Expression Definition	
The form for an expression is <item1> <operator> <item2>. <Item1> can be a tagname, reg:bit, or system TIME, DATE, DAY. <Operator> can be =, !=, >, >=, <, <=, <Item2> can be a tagname, constant, status, reg:bit, HH:MM:SS(time), MM-DD-YY(date), or MON, TUE, WED, etc.	

Device Block Statements

WAITAND	Wait for time or logical AND of pattern
WAITOR	Wait for time or logical OR of pattern
WAITNOT	Wait for time or change of pattern
DELAY	Wait for constant or external variable time period
MSG	Send message includes tag & step
GOTO	Unconditional go to step number
SETF/CLRF	Set/clear global or local flag
GOSET/GOCLR	Go to step on flag set/clear
OUTPUT	Output contact pattern
SETDEBUG/CLRDEBUG	Turn trace on/off
SETERROR/CLRERROR	Set/clear error flag & send message

Test & Jump Statements —

These statements compare two items or values and then go to another statement in the program. Statements provide the ability to execute tasks at a specified time, day of the week, or date.

Debugging Statements —

A SETERROR statement sets error codes for each program block. Then, during execution, the program prints each step number as the step is executed.

Device Block Configuration

The Device block simplifies operations by grouping sensors and equipment together into a logical unit. The logical unit contains the digital signals that turn the equipment on and off, the confirmation signals, the time limit for confirmation, and signals that cover any error condition. After defining the way the logical unit works, the Program block determines the way the Device block will be used in any particular recipe. For example, a valve may always confirm that it is open in 5 seconds, but the valve may be open for 5 minutes in one recipe and 18 minutes in another recipe.

Recipe Generation and Loading —

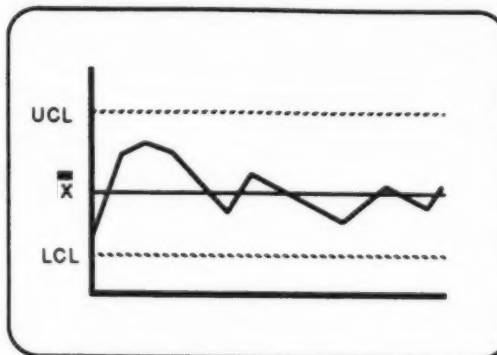
The Batch Control package contains a Recipe package that gives you a powerful tool to simplify operations in multiple product and multi-purpose plants. All the control parameters for any batch operation can be saved in a single recipe. This recipe can then be loaded in a single step or even automatically. The Recipe package speeds development work in pilot plants because it allows you to change parameters and save the values in a new recipe in a single step. Tag groups enable you to use one recipe for multiple sets of I/O points. You can also create a single interactive display in VIEW to support the different sets of I/O points.

The Recipe package is also available as a separate option.

Statistical Control

Statistical Process Control: quality assurance — automatically & on-line

How do you correlate process measurements with product quality? How do you know if your test samples are giving you an accurate picture of your production line? How can you catch your product before it goes out of tolerance and take corrective actions? With Statistical Process Control (SPC), you can calculate process tuning changes and control statistical alarms on-line. Along with X-bar and R control charts and database access, THE FIX SPC package gives you a powerful combination of tools to perform state-of-the-art statistical process control.



On-line Sampling — The Statistical Data block can collect and analyze statistical data via three different modes: manual mode, automatic mode and THE FIX database access program. In manual mode, data is entered by the operator through the CRT keyboard. This is a convenient way to handle data during start-up operations. In automatic mode, the Statistical Data block automatically takes measure-

ments from almost any block within THE FIX. With THE FIX database access program, the block also accepts data from other computers and instruments.

On-line Control — The Statistical Control block acts as a supervisory controller, making changes to the control parameters to optimize quality. The Statistical Control block receives

data from the Statistical Data block and calculates a process adjustment based on the average offset and rate of deviation from a target value. The Statistical Control block can output this value to an Analog Input, Analog Output, PID, or Ramp block.

On-line Statistical Alarming
The Statistical Data block allows you to select any combination of the six statistical algorithms that generate alarms, including: 1-point X-bar; 1-point range; 3-point X-bar; X-bar trend of runs; X-bar length of runs; and X-bar critical runs. You can also manually enter target X-bar values.

A tuning link in VIEW displays the following parameters for a statistical data link:

X BARBAR	:	55.05
X BAR	:	55.55
R BAR	:	5.86
UCL-R	:	10.00
UCL-X	:	60.00
LCL-X	:	50.00
R-1 POINT ALM	:	OK
X-1 POINT ALM	:	OK
X-3 POINT ALM	:	OK
TREND OF RUNS	:	DISABLE
LENGTH OF RUNS	:	DISABLE
CRITICAL RUNS	:	DISABLE
A/M STATE	:	AUTO
OBS/GROUP	:	15
OBS ENTERED	:	10
GRPS ENTERED	:	14
CONTROL LIMITS	:	DONE

Dynamic Control Displays — The Statistical Control package provides on-line tuning and display of control and alarm parameters. The display screen shows the X-bar and range values and the upper and lower control limits. With tuning links, the displays give you an interactive window into the process. Any changes that you make to the control parameters are instantly reflected on the screen.

I/O Drivers: can we talk?

Intellution's I/O driver software is your link to the outside world. Whether you have data acquisition systems, programmable controllers, control subsystems, self-tuning controllers, smart transmitters, special purpose hardware, or control networks, THE FIX speaks their language.

Easy Interfacing — Intellution continues our policy of making configuring a system easy with fill-in-the-blank I/O drivers. You select the block sizes, data types, baud rates, reply time-out values and more, all from a menu that is customized for your particular device. The FIX I/O Drivers support single- and multiple- value transfers for quick and efficient communication.

Selective Communication —

The I/O View option gives you read/write capabilities to controller registers and bits, but only when their read/write windows are on display. Communication starts when a display is called up; it ends when the display is removed. This minimizes the communications load and increases the number of points that you can define.

Multiple Device Support —

With THE FIX you can have up to four different I/O drivers from four different vendors running simultaneously. This means you can buy the best data acquisition and control device for your application without worrying about communicating between them.

Drive-It-Yourself —

Intellution provides a wide variety of serial and parallel drivers for many of the most popular data acquisition devices and programmable controllers. Intellution realizes that there are specialized instruments and other devices that you may need for your application. In order to meet this need, we have an I/O

CURRENTLY AVAILABLE I/O DRIVERS*

I/O DEVICE	BUS	SERIAL	ICM-4	ACE
Allen-Bradley — PLC-3 with S4A/GA	X	X	X	X
Allen-Bradley — PLC/PLC-2	X	X	X	X
Allen-Bradley — PLC-5	X	X	X	X
Acrosystems — Acro 900	X	X	X	X
Action Instruments BC-10	X	X		
Action Instruments I/O cards	X			
Analog Devices — Mac-4000/5000	X	X	X	X
Analog Devices — Mac-6000	X			
Barber Coleman — 560/FCS 8000/990	X	X	X	X
Burr-Brown — PCI-20,000	X			
Computer Products — RTP	X			
Digitronics SIXNET	X			
EIM Valve Controller	X	X	X	X
Foxboro Programmable Controller	X	X	X	X
Foxboro 760/761	X			
Foxboro 99SC/99UCB	X	X	X	X
Fuji Electric — Master Controller	X			
Fuji Electric — Compact Controller	X	X	X	X
with CCS Remote Configuration Program				
Fuji Electric — Real-Time Controller	X	X	X	X
GE Series 6	X	X	X	X
Gould Modicon Modbus I	X	X	X	X
Honeywell TDC 2000/3000 with PCSI	X			
Honeywell Gateway†	X			
Hewlett-Packard 3852A with HP-IB interface	X			
IBM Data Acquisition Adapter	X			
Moore 352/320	X			
Opto-22 Optomux	X	X	X	X
Siemens-Allis MC-16	X			
Square D Sy/Max	X	X	X	X
Tecmax TX410	X	X	X	X
TI TIWay with host interface	X	X	X	X
TI 520/530/560/565 Direct	X	X	X	X
TI 550 Direct	X	X	X	X
Triconex Tricon	X	X	X	X
Westinghouse Numalogic	X	X	X	X

† Available only from Honeywell PCD

Driver Toolkit that lets you write your own driver.

The Hardware Helper — FIX serial drivers are also available for downloading and execution in IBM's

ARTIC board and in an optional Intelligent Communications Module (ICM-4). The ICM-4 board is listed under accessories and the ARTIC board is discussed under the ACE product.

*Consult your authorized FIX distributor for other driver options

THE FIX Catalog of Intelligent Solutions

The FIX ACE

*Drop a powerful new engine into your
IBM PC control system*

When databases get large and control parameters get tight, THE FIX Application and Control Engine (ACE) is the intelligent solution. THE FIX ACE turns the ARTIC board from IBM into a dedicated industrial control co-processor that runs faster with

*breaks the memory
and speed barriers
of the personal computer*

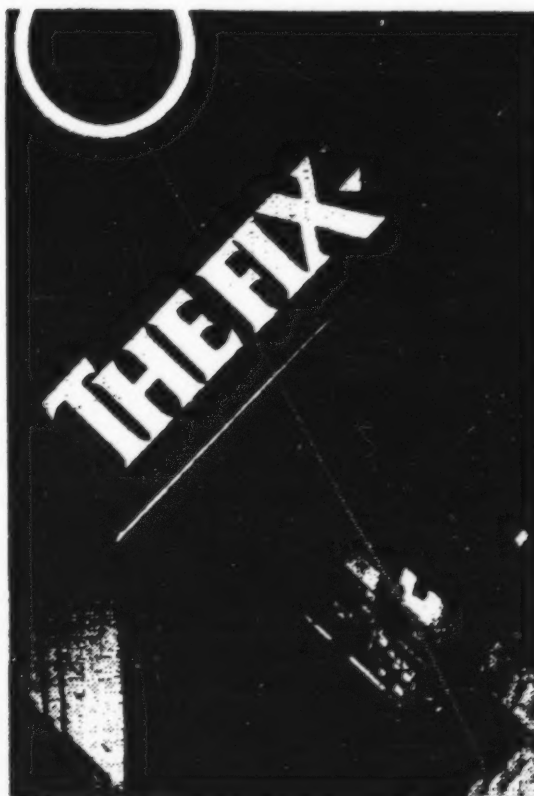
larger databases. At the same time, your personal or industrial computer has complete and transparent access to the process database. ACE frees up 300K of memory in the host computer to run applications without compromising your process control. It's almost like adding a PC within your existing PC.

*free PC memory
for better process analysis*

ARTIC — ACE supports IBM's ARTIC board that contains an 80186 processor, up to one megabyte of memory, and two I/O ports.

THE FIX ACE — THE FIX ACE software places the process database, the Scan Alarm and Control (SAC) module, and the I/O Drivers on the ARTIC board. This means that the 80186 performs only process control and does not perform any system overhead. THE FIX ACE makes full use of ARTIC's multi-tasking operating system for task prioritizing and scheduling.

Invisible — THE FIX ACE downloading functions are entirely invisible to the user. Displays and databases will look the same as for a FIX system;



the only differences are that you can create faster scan times and your displays will update faster with larger databases.

Compatibility — THE FIX ACE is compatible with all FIX databases and graphics. With the exception of parallel I/O drivers, most FIX options are available in ACE versions. Consult your authorized FIX distributor for availability.

Touch Screen Support — Put link selection at your fingertips with Touch Screen Support, a standard feature for FIX ACE. Touch screens make link selection fast and easy for your operator — simply touch the link you want and it is selected. FIX ACE supports a Microtouch Touch Screen (serial version).

Distributed Control Network



THE FIX DMACS (Distributed Manufacturing Automation Control Software) is the first personal computer-based software to provide true distributed control. More than a system of multiple workstations or file-sharing by computers, DMACS offers the comprehensive distributed process control functions that are required by real industrial applications. DMACS delivers multistation operation, distributed processing, and a method for limiting process upsets due to equipment malfunctions. It also allows for system growth over time with minimal changes to software.

Distributed Control — Distributed Control enables the engineer to run a user-written program from his/her office, even if the database resides in a PC on the factory floor, without recompilation or reconfiguration. Distributed control also allows the PC in the engineer's office to modify any parameter, while a PC in inventory might be configured to have read access only to product quantity. Above all, distributed control extends beyond the confines of the PC network to provide data to mainframes or central file servers via other networking applications.

Data Communications — DMACS's efficient data transfer system provides immediate control never achieved with file servers. With DMACS, a PC can directly request as little as a single bit of information from any other PC, with no intervening "master" terminal. Moreover, DMACS "bundles" data requests so that multiple data packets from another PC are fetched in a single trip. DMACS's meticulous design makes

data transfer occur on an as-needed basis rather than on a blind, routine broadcast basis. The result is uncluttered lines and more CPU time free for executing application software.

Independent Nodes — DMACS is designed so that each node in the network has its own database to control its own local functions. In addition, each node has a list that can reference any other database in any other node in the network. The result is that any terminal has the potential to perform any function within the network. The engineer adds security by defining each terminal as a control node (interface with programmable controllers and other I/O devices for direct process control), or a display node (operator interface with full read and protected write capacity for limited control). If the need arises, these terminals can be reconfigured on-line by the systems engineer.

*for more information
see THE FIX DMACS
Networking Software
Product Brief*

Hardware — DMACS fits comfortably into your current and future hardware configurations and does not require any additional proprietary hardware. Existing plant equipment and programmable controllers run smoothly with DMACS. Despite variations among the different NETBIOS-compatible networks, DMACS is designed for compatibility with all of them, including PC-NET, PC-RING, Novell, or 3Com's Ethernet. In addition, DMACS can be run on both IBM-PCs and the new PS/2s, within the same network.

THE FIX DMACS Product Specifications

Network Hardware:	NETBIOS-compatible
Network Speed:	Hardware-dependent (equal or greater than 2 megabaud)
Physical Area Covered:	Hardware-dependent (PC-Network has 1000-ft radius)
Number of Active Nodes:	16 with current hardware
Node Types Supported:	Configuration, display, control
Communication Techniques	
Node to Node:	By tagname and data element; can be optimized with transfer by exception
File Server:	Supported but not required
External Computers:	File transfer to mini and mainframe; IBM computers with 3270 emulator and the 5250 communications interface; DEC VAX systems with DECnet DOS
Operating System:	PC-DOS Version 3.2 or higher; IBM ARTIC, PS/2 supported with proper hardware
Memory Requirements:	640K minimum

THE FIX Catalog of Intelligent Solutions

Open Architecture

Build the system that suits your exact needs

Easy to Customize — Intellution knows that THE FIX, even with all its features and options, may not perfectly fit your unique application. From the beginning, THE FIX was designed with an open architecture so that you could share the process data with other user-written programs or with an off-the-shelf spreadsheet, database, or statistical program. If you have a specialized instrument in your control loop, THE FIX with its open architecture enables you to read instruments' output, analyze that data with your own program, and write the result back into the database.

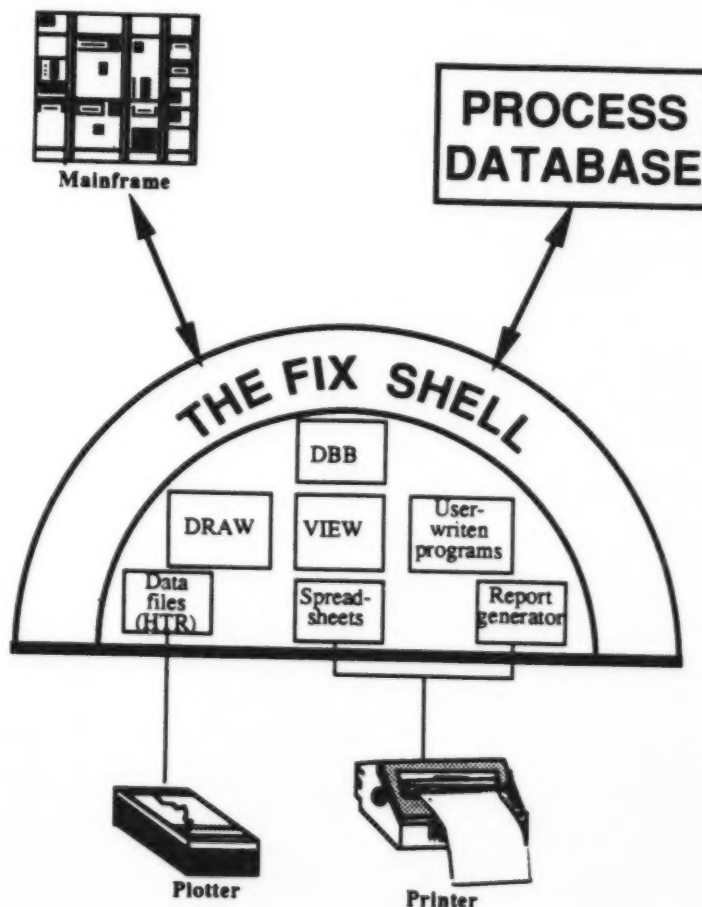
Database Access — The Database Access modules provide real-time read/write access to most values in the process database. You use tagnames to access data, making it flexible and easy. The access routines interlock with the rest of the FIX modules to provide data security.

Help Files — The multi-level on-line help screens for THE FIX can be customized to suit your needs. This feature is ideal for handling special applications, OEM requirements, and native languages.

On-line Spreadsheet Interface With the On-line Spreadsheet Interface (OSI), you can read and write process data between a spreadsheet and the FIX process database. The OSI option also transfers data from THE FIX to other IBM application programs. With the OSI, you develop a display that becomes your data file format. You direct the data to a disk file where it can be imported by a spreadsheet or other program. Alternatively, the data can be transmitted to another computer.

I/O Driver Toolkit — The I/O Driver Toolkit gives you a straightforward method for creating your own real-time I/O drivers for THE FIX. The I/O Driver Toolkit is the foundation for all FIX drivers and contains interface subroutines for the process database, Database Builder (DBB) menus, and the Scan Alarm and Control (SAC) modules. With the Toolkit, you create a high-priority I/O program that is interrupt-driven, just as SAC is. The Toolkit supports both serial and PC-bus drivers.

The FIX Shell — The FIX Shell is a multitasking PC-DOS executive that expands the capabilities of THE FIX. With the FIX Shell, you can run other programs concurrently with the data acquisition programs of THE FIX. The FIX Shell maintains the look and feel of THE FIX with user-built menus, help screens, keyboard security, and high resolution graphics support. The FIX Shell also gives you 17 priority levels and windows for background programs.



Historical Trending

History in the making

The Historical Trending Package provides an automatic and comprehensive means of sampling, storing, and displaying process data over long periods of time. Data collection runs automatically on-line in the background of THE FIX. All the data can be exported to files that can be read by other application programs.

*a comprehensive
data collection
and display package*

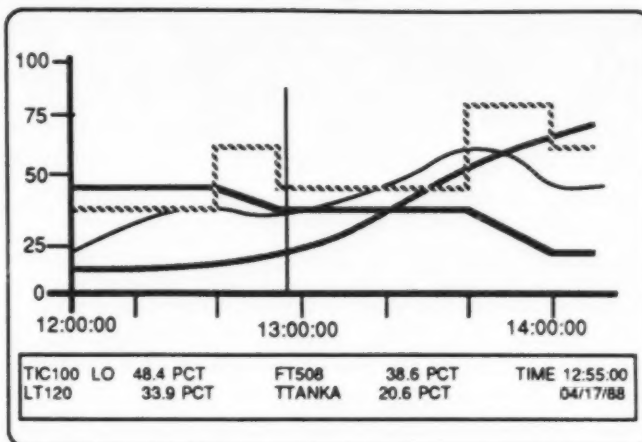
Trend Assignment — With the menu-driven Trend Assignment program, you specify the tagnames of each data point that will be collected. The sample frequency can be as fast as every two seconds or as slow as once an hour.

Trend Collection — The Trend Collection program automatically samples data from the process database according to the information you provide with the Trend Assignment program. The collected data for each point is stored in a time/date-based disk file along with the point's tag name, value and status, and the time of

collection. Trend Collection runs in the background under The FIX Shell. Trend data can also be sent to file servers on a local area network (LAN).

Trend Display — The Trend Display program lets you view up to eight points on a single time line in full color. The program has a number of powerful features, including: chart shift, engineering units scaling, screen compression (pan), and screen expansion (zoom). A movable time cursor provides an exact value/status readout of selected points.

Data Exporting — Data collected by the Trend package can be exported to other packages in a variety of ways. Data on the trend display can be sent directly to Lotus-readable files, as well as ASCII files. A set of subroutines is included with the Trend package, and can be accessed by user-written 'C' programs. These subroutines provide decompression and delivery of any values in the Trend data files. A Trend Reporting program is also included for generating hard-copy reports from the Trend data.



Historical Trending Specifications

Maximum Number of Points:	500	Data Compression Technique:	Deadband
Fastest Collection Rate:	2 seconds	File Size:	2, 4, 8, 24 hrs
Fastest Storage Rate:	2 seconds	Maximum Length of Collection:	Limited only by disk space
Slowest Storage Rate:	1 hour	Display Resolution:	640 x 200 or 640 x 350
Collection Mode:	Sample or Average	Number of Points Displayed:	1 to 8
Data Export Formats:	ASCII file	Time Width of Screen:	2 seconds to 99 days
	Lotus PRN file	Display Colors:	8
	C-subroutine	Display Functions:	Pan, zoom, chart shift, grid
	Printed reports	Display Groups:	User-defined

THE FIX Catalog of Intelligent Solutions

Options and Applications

Intellution provides a full line of optional software that takes advantage of special hardware or performs a specific function

Options

IBM 7552 (Gearbox) Support

With the optional Gearbox Support package, THE FIX takes advantage of the power failure recovery and program-saving features of the 7552 Industrial Computer. During short-term power failures, the Gearbox option provides complete recovery. In the event of a longer failure, the database will be saved in a special file that can be automatically loaded upon restart. Special program blocks can be configured to qualify the system restart for your particular application.

The Report Generator and Scheduler — The Report Generator produces operations and management reports automatically in any format you choose. You can schedule the reports to run at either a preset time or in response to a particular event. The report can contain current, historical, and statistical values. The Report Generator runs in the background of the Shell and uses the Scheduler to trigger generation. The Scheduler also allows you to automatically start background tasks such as user-built "C" programs that access the database.

The On-line Report Package Three on-line reports are included in the Report Package that report on the status of the database blocks. They are block off-scan report, block off-normal report, and block off-alarm report. These reports can be executed from the FIX Shell or they can be executed on demand from the operator's keyboard. Source code is included to allow you to make changes to the report structure.

Graphic Print Program —

Used with the Character Graphics DRAW package, the Graphic Print Program lets you take a "snapshot" of the real-time process graphics on an Epson (or compatible) printer. Every graphic element is displayed on the printout, and the printout is oriented sideways to give maximum clarity. Pixel DRAW contains its own print screen feature.

Recipe Program — The Recipe module of the Batch Control package can also be purchased separately. The Recipe programs will work with any of THE FIX configurations and provide the same ability to define, save, and load recipes for different products.

Remote View — Remote View allows you to access the process database with a VT-100 (or equivalent) terminal. Physical connection is over an RS-232 line from a standard IBM serial communications port. The terminal can view and interact with displays independently of the host computer. Note that Remote View displays all characters in ASCII format, and Pixel Graphics are not supported.

Application Programs

Intellution has created application programs to handle special tasks. These programs are in "C" and usually operate in the background, leaving the foreground free for the operator interface.

Automatic Recipe Download

The Automatic Recipe Download will load a recipe based on an analog input value. It can access up to 3000 different recipes. The source code is included for user customization.

PLC Message Interpreter —

The PLC Message Interpreter displays a message to the operator based on an analog input value. The program allows you to store up to 3000 different messages. The source code is included for user customization.

Energy Management Program —

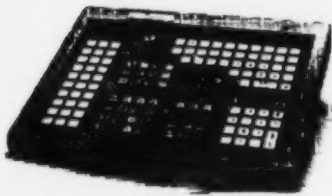
The Energy Management program provides demand management and scheduling for HVAC equipment. This program schedules operations by time of day and day of week with user-definable holiday exceptions. The program monitors power consumption and limits operations based on duty cycles, equipment priority, and monthly target values. The program can calculate the peak demand even if a synchronization pulse is not provided by the electric company. The program works with all versions of THE FIX and operates in the background of THE FIX Shell.

Accessories and Services

Accessories

Even the best software can run better with an additional piece of hardware. Here are a few items that we sell to make THE FIX meet your needs better.

Industrial Functional Keyboard



The Industrial Functional Keyboard continues Intellution's tradition of providing powerful monitoring and control features in an easy-to-use and economical package. All the process control and monitoring features of THE FIX are tied into 64 labelled and color-coded keys. Starting cascades, adjusting setpoints, ramping output values, responding to alarms, controlling displays and more can each be done with a single key. The keyboard can even be tailored to your specific needs with 30 function keys that you can tie to key macros and label.

Intelligent Communications Module (ICM-4) — The ICM-4 increases the communications speed by putting the serial I/O driver routines onto a 8088 processor tied to 256K of dual-ported RAM. Having the I/O drivers on the ICM-4 means less overhead for the CPU in the PC. The ICM-4 also saves space because it can be configured for up to four RS-232 ports, each with a different I/O driver. ICM-4 initialization software is included with many of the popular I/O drivers available from Intellution. The

ICM-4 occupies one slot in the IBM XT or AT.

Mouse — A mouse makes drawing Pixel graphics displays easier and quicker. The mouse is available in two versions: 25-pin and 9-pin for RS-232 ports. It requires no separate power supply or Desktop tablet. Please specify model when ordering.

Note that the PS/2s support 25-pin mice via the RS-232 port, but not via the special mouse port. Consult your authorized FIX distributor for advice on which mouse will fit your needs.

Lattice "C" Compiler — The Lattice "C" Compiler is the only compiler that is 100% compatible with THE FIX. Due to changes made in different versions of the Lattice Compiler, please contact Intellution or your authorized FIX distributor for the proper FIX/Lattice cross reference.

Demonstration Software

The best way to see the power and versatility of THE FIX is with a demonstration program.

Quick FIX — The Quick FIX is a demonstration package that provides a guided tour through THE FIX with explanations and illustrations. The package allows you to actually interact with the major components of THE FIX. You can build and link databases with displays. The Quick FIX requires a hard disk drive or two floppy disk drives and a color monitor.

FIX Demo Package — The FIX Demo Package is a FIX system without the I/O module. With the Demo Package, you can fully appreciate the FIX's power and capability.

Services

At Intellution, our job has just begun when we make the sale. We want to make sure you're as happy with your software two months after the sale as you are before the sale. To help you to start up your system smoothly, we offer the following services:

Training — When you buy your FIX package, our four-day training session will give you complete hands-on instruction on how to set up your system. Our in-house training center features PS/2 computers and modern audio-visual aids. Classes are limited to 16 students so your instructor can make sure you understand every facet of THE FIX. On-site training is available for a minimum of six people. Consult your authorized FIX distributor or the Intellution Training department for prices and terms.

Customer Support — Help in setting up your system is only as far away as your telephone. Our Customer Support group will walk you through solutions to any problems you may have in setting up your system.

Systems Engineering — Even the FIX, with all its flexibility, may not fit your application as precisely as you might like. Our Systems Engineering group will add the features that make THE FIX conform to your specifications and needs. We can create a special driver, scheduling device or other program to make your system just the way you want it.

THE FIX Catalog of Intelligent Solutions

Product Listings

FIX Base Packages

Baseline SCADA

The Baseline SCADA package provides a complete process monitoring package that performs data acquisition, analog and digital alarm detection and message generation, real-time trending, on-line calculations, and interactive color graphics.

Baseline SCADA Package Specifications

Versions: Standard, ACE, and DMACS
Blocks Supported: Analog input, Analog output, Digital input, Digital output, Boolean, Real-time trend, and Calculation. All I/O blocks support dummy (internally calculated) points and programmable controller registers/coil bits.
Number of Blocks: 400 to 500, depending on block types
Graphics Support: Character graphics standard, Pixel optional
Expansion: None

Expanded SCADA

The Expanded SCADA package is the foundation for the most complete PC-based process monitoring and control package available. The package contains advanced data handling and I/O communications functions and can be upgraded to include sophisticated continuous, batch, and statistical process control packages.

Expanded SCADA Package Specifications

Versions: Standard, ACE, and DMACS
Blocks Supported: Analog input, Analog output, Digital input, Digital output, Boolean, Real-time trend, Calculation and Totalizer. All I/O blocks support dummy (internally calculated) points and programmable controller registers/coil bits. Supports read/write (word and bit) access for register values and coil values, depending on I/O driver.
Number of Blocks: 2000 to 3500, depending on block types
Graphics Support: Character graphics standard, Pixel optional
Expansion: Continuous Control, Statistical Process Control, Batch Control
Options: All

Runtime System

The Runtime system reduces the cost of multiple FIX installations. The Runtime version of THE FIX contains all the database features of the Expanded SCADA package except for the Database Builder (DBB) and the graphics display builder (DRAW). You build databases and displays with a complete SCADA package and run them on another computer with the Runtime system.

Runtime System Specifications

Versions: Standard, ACE, and DMACS
Blocks Supported: All FIX blocks
Prerequisites: Uses databases, displays, recipes, and reports built by a FIX Expanded SCADA package.

Product Listings

Expanded Control Packages

Continuous Control Package Specifications

Versions: Standard, ACE, and DMACS
Blocks Supported: Drum sequencer (Standard and ACE only), Setpoint/output ramp, PID control, On/off control, Ratio/bias, Signal selector, Lead/lag, Deadtime
Prerequisites: FIX Expanded SCADA package

Statistical Process Control Package Specification

Versions: Standard, ACE, and DMACS
Blocks Supported: Statistical data and alarm, Statistical control
Prerequisites: FIX Expanded SCADA package

Batch Control Specifications

Versions: Standard, ACE, and DMACS
Blocks Supported: Drum sequencer (Standard and ACE), Setpoint/output ramp, PID control, On/off control, Ratio/bias, Signal selector, Lead/lag, Deadtime, Device, Program
Prerequisites: FIX Expanded SCADA package

Continuous Control

The Continuous Control package allows you to build control loops using traditional control blocks. These blocks have all the features process engineers are familiar with, including cascading, on-line loop tuning and phasing, and PID control. Complex timing requirements are supported with the Ramp, Lead/lag, and Deadtime blocks. On/off control and Signal selector blocks convert analog signals from sensors into direct digital control.

Statistical Process Control

The Statistical Process Control package provides automatic, on-line statistical sampling with alarming and supervisory control on closed loop systems. The package also gives the operator X-bar and range chart displays.

Batch Control

The Batch Control package lets you build complex control loops involving sequencing, wait statements, and test and jump statements. Included in the program statements are a complete set of on-line debugging tools. There is a Device block that lets you tie a group of sensors and equipment together. The Batch Control package includes easy-to-use Recipe Build and Load programs. In addition, Batch Control contains all the blocks included with the Continuous Control package.

THE FIX Catalog of Intelligent Solutions

Product Listings

Options

THE FIX ACE

THE FIX Application and Control Engine (ACE) transfers the process database, I/O drivers, and SAC to the IBM ARTIC board. The ARTIC board is available only from IBM and must have the additional operating system software known as Realtime Control Program (RCP) DOS support (included with the ARTIC board).

There are several versions of the ARTIC board. Each version has a different memory and port configuration.

To select the proper board for your application, you need to know the size of your database. The information at right has been provided as a guide to board selection. Consult your authorized FIX distributor for advice on your particular system.

Distributed Manufacturing and Automation Software (DMACS)

THE FIX DMACS (Distributed Manufacturing Automation and Control Software) is the first personal computer-based software to provide true distributed control. More than a system of multiple workstations or file sharing by computers, DMACS offers the comprehensive distributed process control functions that are required by real industrial applications. DMACS delivers multistation operation, distributed processing, and a method for limiting process upsets due to equipment malfunctions. It also allows for system growth over time with minimal changes to software.

THE FIX ACE Specifications

Program Compatibility:	Uses ACE versions of all FIX packages and options
File Compatibility:	All FIX database and picture files
Scan Time:	0.1 - 255 seconds
Poll Time:	0.1 seconds
Database Size:	Up to 500K

Choosing the Proper ARTIC Board

--Model--	--Database Size--
512K/2ports	Up to 300K
1M/2ports	Up to 500K

THE FIX DMACS Specifications

Network Hardware:	NETBIOS-compatible
Network Speed:	Hardware-dependent (equal or greater than 2 megabaud)
Physical Area Covered:	Hardware-dependent (PC-Network has 1000-ft radius)
Number of Active Nodes:	16 with current hardware
Node Types Supported:	Configuration, display, control
<u>Communication Techniques</u>	
Node to Node:	By tagname and data element; can be optimized with transfer by exception
File Server:	Supported but not required
External Computers:	File transfer to mini and mainframe; IBM computers with 3270 emulator and the 5250 communications interface; DEC VAX systems with DECnet DOS
Operating System:	PC-DOS Version 3.2 or higher; IBM ARTIC, PS/2 supported with proper hardware
Memory Requirements:	640K minimum

Product Listings

Options

Historical Trending Specifications

Versions:	Standard, ACE, and DMACS
Points collected:	500 maximum
Collection Mode:	Sample or average
Data Compression:	Adjustable deadband/limit filters
File Size:	2, 4, 8, or 24 hrs
Length of Collection:	Limited only by disk size
Points Displayed:	8 maximum
Display Functions:	Pan, zoom, chart shift, grid
Data Export Formats:	ASCII file, Lotus PRN file, C-subroutine, printer

The FIX Shell Specifications

Versions:	Standard, ACE, and DMACS
Priority Levels:	17
Keyboard Security:	Reboot lockout

Database Access Specifications

Versions:	Standard, ACE, and DMACS
Languages:	The "C" language
Prerequisites:	The FIX Shell is recommended but not required

On-line Spreadsheet Interface Specifications

Versions:	Standard, ACE, and DMACS
Data Transfer:	To user-definable file format

I/O Driver Toolkit Specifications

Versions:	Standard, ACE, and DMACS
Communications:	Serial and IBM PC-bus ICM-4 card ARTIC card Standard serial port

Historical Trending

The Historical Trending package provides automatic sampling, storing, and displaying of process data over long periods of time. The program runs in the background of The FIX Shell. Trend displays show current and historical data.

The FIX Shell

The FIX Shell is a multitasking executive that allows other programs to run concurrently with the data acquisition and control of THE FIX.

Database Access

The Database Access modules provide real-time read/write access to the values in the process database. Access is by tagname and is interlocked with the rest of THE FIX modules for data security.

On-line Spreadsheet Interface

The On-line Spreadsheet Interface allows read/write access between a spreadsheet and THE FIX process database.

I/O Driver Toolkit

The I/O Driver Toolkit contains interface subroutines to build a custom I/O driver. The I/O driver subroutines allow real-time read/write access to the process database for both serial and IBM PC-bus communications.

THE FIX Catalog of Intelligent Solutions

Product Listings

Options

IBM 7552 (Gearbox) Support

The IBM 7552 (Gearbox) Support program utilizes the power failure and recovery features of the 7552 industrial computer. It includes an automatic restart feature that tests for user-specified conditions.

Versions:
Prerequisites:

IBM 7552 (Gearbox) Support Specifications
Standard and DMACS
Automatic restart requires Batch Control

Free-format Report Generator

The Report Generator and Scheduler provides automatic report generation. The reports are free-format and can contain current, statistical, or historical data. The Scheduler will automatically start background programs on a weekly or monthly basis or in response to a particular time or event. The scheduler can be configured to make the most efficient use of memory, and can automatically exit VIEW to free up more memory to run scheduled events.

Versions:
Prerequisites:

Free-format Report Generator and Scheduler Specifications
Standard, ACE, and DMACS
Requires the FIX Shell

Remote View

The Remote View program allows a VT-100 (or equivalent) terminal to access the process database. The access is independent of any tasks running on the host computer and operates via RS-232 communications. Remote View is limited to Character graphics displays. Graphics characters are translated into their ASCII/numeric counterparts. All character graphic links will be displayed as they are in the PC.

Versions:
Communications:
Data Links Accessible:

Remote View Specifications
Standard and ACE
RS-232 from a standard IBM serial port
All ASCII, non-pixel data links

Graphic Print Program

The Graphic Print program sends Character VIEW displays to an Epson printer.

Versions:
Printer:

Graphic Print Program Specifications
Standard only
Epson or compatible

Product Listings

Options

Recipe Builder and Loader Package Specifications

Versions: Standard, ACE, and DMACS
 Number of Control: 3000
 Parameters:
 Number of Recipes: 3000
 Security: Interlocking supported

Automatic Recipe Download Specification

Versions: Standard, ACE, and DMACS
 Number of Recipes: 256
 Customization: Yes - source included
 Prerequisites: The FIX Recipe Builder and Loader package

Energy Management Program Specifications

Versions: Standard, ACE, and DMACS
 Number of Schedules: 8
 Demand Calculations: Pulse and sliding window

Lattice "C" Compiler Specifications

Compatibility: 100% compatible with THE FIX
 Versions: Depends on the version of THE FIX

Downtime Monitor

Versions: Standard (check for availability of other versions)
 Units of time: hours, minutes
 Maximum number of timers: 50

Recipe Builder and Loader Package

The Recipe Builder and Loader package stores and loads process variables as a single recipe. The program supports interlocking. This package is standard with Batch Control.

Automatic Recipe Download

The Automatic Recipe Download program loads a recipe based on an analog input value (PLC register). This program extends the automation capabilities of the Batch Control package in multi-product and multi-purpose plants.

Energy Management Program

The Energy Management Program monitors demand and operates HVAC equipment based on priority schedules, duty cycles, and monthly target values.

Lattice "C" Compiler

The Lattice "C" Compiler is the only compiler that is 100% compatible with THE FIX. Due to changes in different versions of the Lattice compiler, please consult Intellution for the proper FIX/Lattice cross reference.

Downtime Monitor

The Downtime Monitor (DTM) records the duration between real-time events in the FIX process database. The resulting time is stored as an analog value in the process database.

THE FIX Catalog of Intelligent Solutions

Product Listings

Accessories

Industrial Functional Keyboard

The Industrial Functional Keyboard links all the monitoring and control functions of THE FIX to 64 color-coded and labelled keys. In addition to the built-in FIX functions, the keyboard has 30 keys that can be programmed by the user for application-specific functions.

Intelligent Communications Module

The Intelligent Communications Module (ICM-4) increases communication speed by putting the serial I/O drivers onto an 8088 processor on the ICM-4 board. The ICM-4 board can be configured for up to 4 RS-232 ports.

Graphics Mouse

The Graphics Mouse makes drawing Pixel graphics easier and quicker. The mouse is available in two models: 25-pin and 9-pin for an RS-232 port.

Industrial Functional Keyboard Specifications

Environmental:	Designed for NEMA 12 with a chemical-resistant covering
Size:	2.5" x 15" x 19"
Hardware Compatibility:	IBM 7531, 7532, and 7552 industrial computers; and IBM AT and XT286
Software Compatibility:	All versions of THE FIX but versions earlier than 2.2 require an upgrade.
Security:	Four-position lock
Functional Groups:	Display and menus, process control, alarm response, cursor control, alphabetical, numeric, and user-defined
Options:	Rack-mounting kit

Intelligent Communications Module (ICM-4) Specifications

Number of Ports:	Four serial RS-232 ports
Number of I/O Drivers:	Four different FIX I/O drivers
Processor:	8088
Memory:	64K-256K
Host Requirement:	One slot of an IBM PC/XT or AT

Graphics Mouse Specifications

Models:	25-pin or 9-pin
---------	-----------------

Demo Packages

Quick FIX

The Quick FIX is a demonstration package that provides a quick tour through THE FIX. Quick FIX is an interactive program that runs on an IBM PC, XT, AT, or compatible with color monitor and either a hard disk drive or two floppy disk drives.

FIX Demo Package

The FIX Demo package is a FIX system without the I/O module.

Quick FIX Specifications

Requirements:	IBM PC, XT, AT or compatible with a color monitor and either a hard drive or two floppy drives
---------------	--

FIX Demo Package Specifications

Requirements:	IBM PC, XT, AT or compatible with color monitor
---------------	---